CALORIC.

IN TWO VOLUMES.

VOL. I.

"To every form of being is assigned
An active principle: howe'er removed
From sense and observation, it subsists
In all things, in all natures, in the stars
Of azure heaven, the unenduring clouds,
In flower and tree, in every pebbly stone
That paves the brooks, the stationary rocks,
The moving waters, and the invisible air.
* * * * from link to link
It circulates, the soul of all the worlds."

WORDSWORTH.

CALORIC:

ITS

MECHANICAL, CHEMICAL AND VITAL AGENCIES

IN THE

PHENOMENA OF NATURE.

BY

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VOL. I.

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PREFACE

TO THE FIRST EDITION.

In the primitive ages of the world, when men gazed on the wonders of nature with the freshness of childhood, and before the vivid information of the senses had become obscured by fabulous traditions, all their physical and metaphysical theories were founded on the belief that solar fire is the efficient cause of motion and life throughout creation. This belief, so manifestly the result of observation and experience, was constantly forced upon their minds with all the evidence of a living reality; and prevailed for thousands of years in every quarter of the habitable globe. Nor is there anything so strikingly obvious to the unsophisticated common sense of mankind as the omnipresent influence of the sun, which is perpetually exerting a tranquil, yet omnipotent energy, throughout the air, the ocean and the solid ground. He regulates all the phenomena of climate and season, evaporation and rain, the circulation of the atmosphere, the flowing of waters, the transformations of chemistry, the operations of vitality, and the revolutions of the heavenly bodies.

But as the ancients never explained the laws by which elementary caloric operates in the generation of force and motion, nor the manner in which it is related to electricity and

light, their speculations have exerted little influence on the physical theories of modern philosophers, who have, strangely enough, disregarded nearly all that was most valuable in the science of antiquity. At the present time, it remains undecided, whether caloric is an exceedingly subtile and active essence, as maintained by the early Hindoos, Egyptians, Phœnicians, Chaldeans, Persians and Arabians, as well as the more enlightened Greeks and Romans; or whether it consists in mere motion and vibration among the particles of ponderable matter, as supposed by Bacon, Boyle, Hooke, Rumford, Davy, Young and others.

One of the most important modern discoveries was that of latent or combined heat, by Dr. Black. When he proved by accurate experiments, that definite measures of caloric are required to convert solids into liquids, and that the same subtile fluid is obtained from the atmosphere by respiration, he laid the foundation of its true theory. But as he did not extend his researches to its agency in the mechanical, chemical and vital phenomena of nature, his labours have not been followed by results corresponding with the magnitude of his discovery,—if we except the improvement of the steam engine by Watt.

Nor has any one, either among the ancients or moderns, ever attempted to give a regular and systematic history of the mode in which caloric operates in all the molecular and aggregate fôrces of matter. Mr. Whewell observes, in his late *History of the Inductive Sciences*, that "we have no hypothesis regarding thermotics, which, being assumed in order to explain one class of phenomena, has been found to account exactly for another." Yet he adds: "it is one of the cardinal points on

which the doors of physical knowledge must turn, which have hitherto remained closed."

Within the last hundred years, electricity has been regarded by many persons as a key by which to unlock all the secret cabinets of nature. We have had electrical theories of chemistry, of life and of the universe. Yet no one has explained what electricity is—whether a separate and distinct agent, a modification of some other exceedingly refined and more comprehensive principle, or a mere effect, condition or property of ponderable matter. The celebrated Faraday at one time adopted the simple and rational theory of Franklin, that it is a material fluid, definite measures of which belong to each element of ponderable matter. And yet he speaks of it very often as if he considered it to be a compound fluid. But when treating of its chemical agency, he represents it as "a modification of the exertion of chemical forces."

Again, when by following up the discoveries of Œrsted, Davy, Arago and Schweigger, who found that electricity is capable of producing all the phenomena of magnetic action on a small scale, he succeeded in obtaining an electric spark from a permanent magnet, he arrived at the conclusion that electricity and magnetism are identical; except that in the latter "the axis of power" is greater than in the former. Yet, as if not satisfied with any of the foregoing hypotheses, he suggests, at another time, that electricity may be resolved into undulations of an ether; and, at another time, that all the more important electrical phenomena may be resolved into polarization of the particles of ponderable matter, or what has been called atomic polarity. But he does not explain what he means by the axis of power and electric polarity; nor how

chemical affinity and magnetism, which are merely effects or modes of action, can be identical with their cause; nor does he inform us what the ether is, and what causes it to vibrate. Such have been the difficulties of this important department of physical science, that its most distinguished votaries have hitherto failed to present us with a consistent theory of electrical phenomena. But I hope to make it appear that most of these perplexities have arisen more from defective methods of inquiry, than from any inherent obscurity of the subject.

Such is the reverence of mankind for mysteries, that the majority are always ready to believe what they do not understand; while the most obscure and visionary fancies are often regarded as profound. It was long ago remarked by Longinus, that darkness is a source of the sublime; and it must be admitted that objects are magnified by looming through a fog.

In all ages of the civilized world, light has been recognized as a powerful agent in the work of the universe. As the great Painter of Nature, it gives to the dome of heaven its azure hue; to the rainbow its gorgeous red, brilliant yellow, refreshing green and lovely blue, shading into the softer violet. It is solar light which touches the morning and evening clouds with its celestial pencil, when they glow with vivid tints of ruby, sapphire and gold. It adorns the flowery fields with an endless variety of enchanting colours; while it is perpetually modifying the taste, odour and other sensible properties of different bodies.

But it is still an unresolved problem, whether light be a material substance, as maintained by Pythagoras, Democritus, Leucippus, Empedocles, Plato, Epicurus, Newton and Brewster; or whether it consists in the mere vibrations of some

unknown ether, as supposed by Descartes, Huyghens, Hooke, Euler, Young, Sir John Herschel, Arago and others. Nor is it yet finally settled whether white light is composed of seven primitive rays, as supposed by Newton, or of only three fundamental colours, red, yellow and blue, as maintained, with many cogent reasons deduced from experiment, by Sir David Brewster. On the same subject, the advocates of the undulatory or wave theory are equally at variance among themselves; for while Huyghens maintained that solar light is composed of only two elementary colours, *yellow* and *blue*, Hooke reduced all its modifications to *red* and *violet;* whereas Young reduced the whole to *red*, *green* and *violet.*

What is still more remarkable, neither of the two great rival parties has ever yet attempted to ascertain the relations of light to caloric and electricity; nor in what way they perform so many wonderful effects in the moving drama of the universe. But if they be connected in the operations of nature, they must be united in theory. And it will be a leading object of the following work to prove, by a careful generalization of facts, that caloric and electricity are mutually convertible into each other; consequently, that they are modifications of one and the same essence, which is the active principle in light, and in all the phenomena of nature.

Since the time of Sir Isaac Newton, it has been generally supposed that all the molecular changes of matter may be referred to attractive and repulsive forces. Yet the cause of attraction and repulsion has not been identified with any known principle capable of demonstration. The orbits of planets, and the times of their revolutions, have been measured with mathematical precision; but the cause of their

eternal motion has never been clearly distinguished from projectile and gravitating forces. The relative magnitudes of the particles or atoms of ponderable matter have been, to a certain extent, ascertained by the refined analyses of modern chemistry; yet the cause of chemical affinity is still confounded with inherent properties, occult qualities and undefined powers. The composition of plants and animals has been discovered, and their intimate structure explored; yet the organizing principle remains a profound mystery. What was said by Descartes two hundred years ago, is equally true at the present day: "In philosophia nihil adhuc reperiri, de quo non in utramque partem disputatur." And Mr. Whewell observes in a very recent work, that "the past history of man, of his arts, of languages, of the earth, of the solar system, offers a vast series of problems, of which perhaps not one has been rigorously solved."

It has been a complaint of long standing in the world, that nature has spread a veil over the first principles of things, which man can never hope to remove. But there is reason to believe that all the great truths of science which are of the highest importance for us to know, are no less remarkable for simplicity, than for the wide extent of their application; and that when fully unfolded, they will be self-evident propositions. It is true enough, that the most familiar phenomena of nature, when viewed separately, or through the mystical interpretation of visionary theorists, are as "inscrutable as the scattered leaves of the Sibyl;" but when traced to their origin, the hidden meaning of everything is gradually disclosed, and order springs from chaos. It was profoundly observed by Sir Edward Bulwer, that "the key to all mystery is the desire

to know,"—and that "there is only a single step from a truism to a great discovery."

If we are destined ever to arrive at a perfect theory of nature, it must be founded on a true history of the Grand Original, and a complete knowledge of the *Prime Mover*. Nor is it possible that men should avail themselves fully of the powers which are in nature, without knowing the cause of these powers. It was from the elastic force of the latent caloric that belongs to nitre, sulphur and charcoal, that man, unconsciously, obtained the power of gunpowder; the invention of which has essentially modified the condition of the human race; for it thenceforward secured the uninterrupted progress of civilization, which can never again be arrested by the incursions of barbarous hordes, nor the light of knowledge be extinguished in embryo, as during the early periods of history. It was by discovering that a piece of metal called the loadstone, when horizontally balanced on a pivot, is constantly directed to certain points in the polar regions, that commerce and civilization have been extended to the remotest parts of the earth. But men have yet to learn that the same principle which directs the compass-needle to the poles, guides the planets in their orbits, and fills them with life.

It was by seizing the grand lever of nature as a moving agent, that man was enabled to create the steam engine, which has brought about a more important revolution in the condition of nations, than all the united discoveries of antiquity for thousands of years. Nor can there be a reasonable doubt that a complete knowledge of the same agent, as it operates in all the phenomena of nature, would augment the resources of happiness an hundredfold, dispel the clouds of error which have so

long hovered over the sciences, and enlarge the empire of man over the material world in an endless variety of ways. It is animating to think how soon this grand result might be brought about, if all the talents now wasted on fruitless speculations were rightly employed in the study of nature.

It may be right to inform the reader that a brief outline of the leading views contained in the following chapters was first promulgated by the author in an essay entitled "*A New Theory of Terrestrial Magnetism*," published at New York in 1833; and somewhat extended in a series of papers in the *Knickerbocker Magazine* of 1834–5. The author also feels it due to himself, and to those friends who have been long expecting this work, to state, that the first three books were originally intended to be published separately, and were actually printed in 1837, the Preliminary Chapter excepted. But as more enlarged views of the subject opened to him, he clearly perceived that a development of the physiological and pathological laws of caloric was essential to the completion of his undertaking; which at that time he supposed would not require more than twelve months:—

> "But more advanced, beheld, with strange surprise,
> New distant scenes of endless science rise."

The performance of this task required a vastly greater amount of laborious research than he was prepared to expect, until he had proceeded too far to desist. In the mean time he had the satisfaction of perceiving that, with every additional knowledge of facts, he was conducted to a more elevated point of view, and to more comprehensive generalizations; the consequence of which has been, that in the Preliminary Chap-

ter, he has entered more fully into the rationale of geological and astronomical phenomena, than he had ventured to do in the Second and Third Books.

In addition to the many difficulties encountered at every step, much precious time was lost owing to ill health, by which the work has been still further and most painfully delayed, to the disappointment of the publisher, whose liberality and forbearance merit the grateful acknowledgments of the author.

DR. METCALFE'S LIFE.

SAMUEL L. METCALFE was born near Winchester, Virginia, on the 21st of September, 1798. His mother's maiden name was Sittler.

When he was quite young, his parents removed to a farm in Simpsonville, Shelby County, Kentucky. There, amid the wild beauties of nature, he grew up healthy in body and mind. At a very early age he was fond of reading, and made rapid advances in every branch of study. He also, as quite a young boy, exhibited a great taste for mechanics, and in his leisure hours amused himself by constructing boats and toys for the children.

It was the intention of his father that he should become a farmer; but the son had higher aspirations.

The boy with rosy cheeks and athletic limbs had grown into a thoughtful youth, who had gazed on, and examined with awe, the wonders of nature, and longed for that knowledge that would explain to him the mysteries that surrounded him. Yet how was he to obtain the means necessary for study?

At the age of sixteen he was skilled in sacred music, and while pursuing his studies in Shelbyville, gave lessons once a week in singing. About this time he wrote a volume of sacred music. The thought occurred to him, that he would publish this work in some large city, and that the profits of its sale should be appropriated to defray the expenses of a collegiate education.

He sought his father, and told him of his plans. The father listened to the enthusiastic youth, but shook his head, saying:—"I cannot con-

sent to so wild a scheme." A few days after, his father called him. "I have been thinking," said he, "of your request. I see your heart is set upon this journey. Go, my boy, and may God prosper you." He started for Cincinnati, and there met with a publisher who sympathized with the young man, and undertook to bring out the work at his own risk; and afterwards gave him a sufficient sum to enter College.

In 1819 he matriculated in the Transylvania University, Lexington, Kentucky; and in 1823 received his diploma as Doctor of Medicine. In the same year he commenced practice in New Albany, Indiana. He afterwards removed to Mississippi, where he married, but became a widower about four years thereafter.

For some time his mind had been pondering on the great subject which in after years so completely engrossed his attention, and in 1831 he visited England, in order to procure certain rare and valuable books, which he wished to consult in the prosecution of his experiments. Unfortunately, this valuable library was destroyed by fire during his second visit to England. After his return home, he made a geological tour through East Tennessee, North Carolina and Virginia.

In 1833 he brought out his work on "Terrestrial Magnetism," which was published in New York, and dedicated to Joseph Delafield, Esq. Before this time, he had written and published a brief work on the Indian wars of the West.

He remained in New York until 1835, occasionally writing articles for the *Knickerbocker*, under the signature of M. But the small volume he had written on "Terrestrial Magnetism" only spurred him on to do more. His mind had caught fire on the subject of Caloric, and he burned with desire again to visit the great British metropolis, there to consult the vast libraries, and work out his theory.

In 1835 he again crossed the Atlantic, and took up his abode in London. Those who knew him there will remember how he worked on courageously, unremittingly, for days, months, years, in succession. His health was delicate, his means were small, but he felt that his election was sure.

In a letter dated 1838, he says:—

"Were it not that the prize of my high calling is *sure*, I should have

sunk beneath the protracted labor of thought which my work demanded. 'Sorrow may endure for a night, but joy cometh in the morning.'"

Again:—

"Be not surprised nor discouraged should you find my work attacked or abused. It is impossible it should escape censure, subversive as it is of a thousand errors that are interwoven with the interests and reputation of men. But 'truth is mighty, and will prevail.'"

In 1841 he writes to his brother:—

"You must not be surprised at the time which I have employed on the present work. Having long since passed the Rubicon, it would be madness now for me to think of anything less than an absolute conquest of the centre and capitol of the sciences. But it is only a small band of intellectual heroes, whose minds have been kindled with fire from the altar of genius, that are capable of understanding the real merit of such a conquest!"

In this trying period of his labours, he was sustained by the sympathy of a few kind friends in London. Their letters to him (which on his death were found among his papers) prove how much he was beloved.

In 1843, Dr. Metcalfe's work on "Caloric" was completed and published by Pickering, London.

The following extract is from a letter written from London by the Doctor to his brother in Kentucky:—

"I have fought the good fight, I have finished my course, and performed the work which Providence appointed for me to do. Whatever its fate may be, I have already secured a place among the benefactors of the human race—a reputation that will go on increasing long after I shall have ceased to live.

"Had I remained at home, I should now, in all probability, be rich, and in an influential position. But in exchange for those honours, I have the gratification to know, that I have added to the stock of knowledge; and that I shall leave behind me an undying name!"

On the 25th of April, 1845, he sailed from London in the ship Brontes, and arrived in New York on the tenth of June. His health was much

benefited by the sea voyage. And now all that he had anticipated was realized; he was at home once more; his book was finished; friendly congratulations greeted him on every side.

In 1846, Dr. Metcalfe was married to an English lady, with whom he became acquainted in London. In the same year he made arrangements with a firm in Philadelphia to re-publish his book; notes which he made on the margin of the London copy are incorporated with the text in the present edition; and now the publishers were ready, and the scientific world expecting it. But that earnest desire to perfect his work, peculiar to creative genius, detained him from year to year. In the mean time his health became delicate, and in the spring of 1856 he took cold, and his lungs became affected. As the summer advanced he appeared to revive, and expressed a wish to go to the sea-side, and in July was taken to Cape May. It was his last journey upon earth. In two weeks from that time he was buried in the country church-yard on Cape Island. He left a widow and one child, a daughter between eight and nine years of age.

E. M.

NOTICES OF THE FIRST EDITION.

The following extracts are taken from some of the reviews on the work alluded to in the preceding sketch of Dr. Metcalfe's life:—

From the London Medical Gazette, May, 1844, pp. 229 and 408.

"It bears the unquestionable stamp of genius, and carries with it, at the same time, evidence of learning various and extensive, and of such laborious research, as can only be successfully achieved by minds of the noblest order in pursuit of sacred truth."

"It is a work, the like of which only comes from the press at rare and distant intervals—a work, indeed, of sublime scope, and, rightly taken, of the noblest tendency."

"It is the spontaneous effusion of a gifted mind, brimful of knowledge, and tinctured itself with the hallowed fire of poetry."

From the New York Journal of Medicine, September, 1845, p. 208.

"The author appears to us to possess a fine philosophical genius. His doctrines and views are so bold and original, so comprehensive in their scope, so clearly set forth, and so supported by facts and reasoning, that they cannot fail to command the attention of the reader."

From the New York Journal of Medicine, July, 1846, p. 75.

"The work resembles the beautiful system of nature which it is designated to illustrate. The longer we examine it, the more beauties do we find in it. The author, we believe, is fairly entitled to the credit of being the first philosopher who has discovered a key whereby to unlock all her secret cabinets of wisdom and wealth."

From the Western Journal of Medicine and Surgery, July, 1846, p. 49.

"If the Doctor succeed in establishing the correctness of his theory, (and we do not oracularly assert that he will not,) he will be one of the most illustrious benefactors of physical science—if not himself the most illustrious—that time has produced. His success, should he achieve it, will be the solution of the *gordian knot,* to effect which many of the master-geniuses of every enlightened era and country have laboured in vain. And whether he succeed completely or not, he will, by virtue of what he has already done, occupy a place among the most eminent writers of the age."

From the same, October 3, p. 19.

"When estimated as an aggregate, by the value in detail of its *inherent* qualities, and by the peculiar nature of certain incidental circumstances which unite with those qualities in giving character to it, this cannot fail to be regarded, by competent judges, as one of the most extraordinary productions of the kind that has issued from the British press during the nineteenth century. Had we said, that has issued from *any press* during *any century,* whose history makes a part of recorded knowledge, it would not be easy to fasten on us the charge of either error or extravagance. We, at least, are compelled to think so, after a very careful examination of the subject. As an inquiry, we remember no instance in which the work before us has been surpassed on sundry points in *depth* and *solidity;* and we challenge refutation, when we add, that, in the *compass and grandeur of its outline, it cannot be surpassed.*"

From the North American Review, July, 1857, p. 40.

"We have prefixed to this paper the titles of two essays, published within the last few years, and also of a *ponderous volume which saw the light before either of them,* and has been, or seems to have been, less read than either. Mr. Grove's essay has excited great attention in England, and received the honours of translation into the French language. Dr. Carpenter's paper, published in the *Philosophical Transactions,* extended the generalization of Mr. Grove into the domain of physiology. Both are brief, and are therefore read.

"Dr. Metcalfe forgot the motto which he must have often seen quoted from D'Alembert: 'The author kills himself in spinning out what the reader kills himself in cutting short.' Consequently, his book has been shelved, in spite of its originality and learning.

"But we must do our countryman the justice to say, that, if there is anything in the physical theory of vital actions which has found advocates in Mr. Newport and Dr. Carpenter, and which Professor Draper has so forcibly illustrated, *Dr. Metcalfe has anticipated them all*, in maintaining that caloric 'is alone, of every form of being, quick or dead, the active principle,' the same doctrine, modernized, which, in another form, was taught by Hippocrates. And we must be permitted to express our astonishment, that a work of such pretensions, published in London, should be ignored by any English writer of authority, while he is repeating and developing its leading ideas, long since given to the world."

PUBLISHERS' NOTICE.

The present edition contains the emendations of the author up to the period of his death. It has, during its passage through the press, been submitted to the supervision of a competent editor, who has revised the text so far as it could be done without essentially changing the sense or language of the author. An appendix, also, has been added, containing some recent facts bearing upon the subject-matter of the work, but which could not have been introduced into the text without taking what might be considered an unwarrantable liberty.

CONTENTS OF VOL. I.

BOOK I.

PRELIMINARY CHAPTER.

CHAPTER II.

CHAPTER III.

BOOK II.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

BOOK III.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

BOOK IV.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CALORIC.

BOOK I.

PRELIMINARY CHAPTER.

"Oh that those who have both time and intellect at command adequate to the investigation, might, in perfect tranquillity, search into nature, until they ascertain what quantities of heat are required to produce every action of matter; that mankind might then not only become masters of every kind of knowledge, but of every kind of power."—TELESIUS.

THAT the reader may perceive at once the general scope and object of the present work, I shall commence with a brief outline of the leading facts, which connect the various operations of nature with the fundamental laws of caloric. But as men of science are still undecided whether caloric be a material agent, or the mere effect of motion among the particles of ponderable matter, it becomes necessary to examine the evidence on which these opposite views have been founded.

Among the most enlightened nations of antiquity, elementary Fire was regarded not only as a most re-

fined and spiritual essence of all the elements, but as an universal and self-active principle, which they considered as identical with existence or being. It has been amply proved by Bryant, Calmet, and other learned etymologists, that the Greek ἐστὶ, and the Latin *esse, to be*, like our words essence and essential, were derived from the Hebrew אש *Esh* or *Es*, the fire; and that *Vesta*, the goddess of that element, had her name from the Chaldee אשתא *Eshta* or *Esta*. They have also shown that the word אם *Am* denoted both heat and existence, among the early Egyptians; who, believing it to be the cause of motion and organization throughout nature, inscribed it on the great door of one of their temples.

We are further informed by the learned and philosophical Parkhurst, that the sacred mystical letters *Iη Ie*, which were inscribed over the door of the temple at Delphi, dedicated to Apollo, (who was a mythological personation of the sun or solar fire,) were taken from the Hebrew יה *Yeh* or *Yah*, signifying existence or being. Nor is it unworthy of notice, that the Greek *πυρ fire*, was derived from the Hebrew פור *pur*, to break, dissolve, and separate; actions which clearly imply mechanical and material agency. So much for the primitive meaning of words employed by the ancients to represent the essential nature of what is called heat, but which I shall generally denominate caloric, for the purpose of distinguishing the cause from the mere sensation of heat. Let us now examine the views which have been entertained by the moderns on this important subject.

In the *Novum Organum*, and in his Treatise en-

titled *De Forma Calidi*, it was maintained by Lord Bacon, (whose opinion has been adopted by many philosophers since his day,) that *the very essence of heat is motion, and nothing else.* In accordance with this doctrine, Sir H. Davy observes, in his *Chemical Philosophy*, that "the cause of heat is motion, and the laws of its communication are precisely the same as the laws of the communication of motion." But in the *Treatise on Life and Death*, as also in his *Natural History*, Bacon maintains that "there is, in every tangible body, a spirit or body pneumatical, which fills the pores of all gross bodies:—that it is not some virtue, or action, or trifle, but a *real* and *quantitative substance*, though rare, invisible, and without weight." Moreover, that this spirit or body pneumatical was only another name for what Hippocrates and other Greek authors called *θερμον heat*, is equally manifest from the fact, that Bacon represents it as the *cause of evaporation*, and of many other effects which are predicable of caloric alone. And Sir Humphrey Davy observes, in his *Agricultural Chemistry*, that "whatever theory we adopt, *it is certain that there is matter moving in the space between us and the heavenly bodies, capable of communicating heat.*" It is therefore evident, that neither of these distinguished men can be fairly ranked as advocates of the immaterial theory; and that, in reality, they had no fixed or settled opinions on the subject.

The authority of Sir Isaac Newton has been often cited in support of the doctrine that caloric is not a material substance. But it is worthy of special notice, that in the latest works of that great man on physical

science, he maintains the existence of what he calls "an exceedingly subtile and elastic ethereal substance, which is diffused through all places, fills the pores of gross bodies, and forms a large constituent of their bulk or volume." In a letter addressed to the celebrated Boyle, in 1678, the object of which was to explain his views of the ether, he represents it as "the cause of cohesion, capillary attraction, and of the force by which menstruums pervade and dissolve solid bodies." He adds in another sentence, "I conceive the atmosphere to be composed of the particles of all sorts of bodies of which the earth consists, *separated and kept at a distance from one another by the same active principle.** But if the ether be the cause of solution, and of the elastic force of the atmosphere,

* The above views were still further expanded in a scholium at the close of the second edition of the *Principia*, published in 1713; and in the form of queries, they were reiterated at the close of the *Optics*, published in 1717. In both of these great works, he represents the ether as the cause of gravity, cohesion, capillary attraction, solution, elasticity, the emission, reflection, refraction, and inflection of light. He also maintained that the ether is the cause of animal motion. Yet he observes, that he knows not what the ether is; and that "we have not that sufficiency of experiments which are requisite to an accurate determination of the laws by which this subtile spirit operates." But if Newton had traced the word ether to its primitive roots, the discovery of its real meaning might have modified all his physical investigations, and have given a totally new aspect to the whole circle of the Sciences. The truth is, that a complete Etymological Dictionary would sweep away innumerable misconceptions, errors, and metaphysical subtleties, which have gradually arisen from the revolutions in language, and the adoption of words the primitive meaning of which has not been understood.

it is manifestly identical with caloric. It is true that in the fifth query, toward the close of the *Optics*, Newton represents heat as consisting in a vibratory motion among the particles of bodies,—and that the whole theory of the *Principia* was founded on the hypothesis that space is a vacuum; which is certainly at variance with the foregoing views of the ether. It is also inconsistent with his doctrine of light, which he regarded as a material substance, perpetually flowing from the sun and fixed stars through space. But that caloric does not consist in mere motion or vibration among the particles of ponderable matter, would appear from the following considerations:—

1. That it may be added to and subtracted from other bodies, and measured with mathematical precision, as all good thermometers demonstrate:—

2. That it augments the volume of bodies, which are again reduced in size by its abstraction:—

3. That it passes by radiation through the most perfect vacuum that can be formed by means of the air-pump, in which it produces the same effects on the thermometer as in the atmosphere:—

4. That it exerts mechanical and chemical forces which nothing can restrain, as in volcanos, the explosion of gunpowder and other fulminating compounds:—

5. That it operates in a sensible manner on the nervous system, producing intense pain, and disorganization of the tissues when in excess:—*

* The same reasoning on which is founded all belief in the material existence of the outward universe applies equally to caloric.

6. That it modifies the forms, properties, and conditions of all other bodies, in an endless variety of ways.*

No metaphysical sophistry can refute the belief of mankind, that whatever operates in a sensible manner upon material organs, must be a real substance; for the obvious reason, that "there can be no virtue without substance," as maintained by Newton. I cannot, however, agree with Epicurus, that nothing exists but what is *visible* or *tangible*, since the ultimate atoms of the grossest matter, in their separate state, can neither be seen nor touched, owing to their extreme minuteness, and yet have a real existence. It is observed by an able writer in the *Church of England Review*, that our words *thing*, and *think*, were derived from the Greek verb θιγγ-εν, to touch; that is, a thing is what we first touch, and then think upon. Yet we may think upon the ultimate atoms of matter, which cannot be recognized by any of the senses until united into aggregates. He adds, that all impressions on the senses are resolvable into touch. But there is nothing in nature which operates so powerfully on the sense of touch as caloric.

> "When Bishop Berkely said there was no matter,
> And proved it—'twas no matter what he said."

And when men say that caloric is not a substance, they reject the evidence of their senses, subvert the foundation of all knowledge, and pave the way to universal skepticism. Yet I cannot wholly agree with Aristotle when he says, that those who deny the reality of an external world, deserve to be chastised rather than confuted.

* It was first ascertained by Dr. Black, that on mixing a pound of water at 172° F. with a pound of ice or snow at 32°, the latter was melted, when the temperature of the mixture stood at 32°; showing that 140° of caloric had been transferred to the ice, and intimately combined with its particles. Since then it has been found, as predicted by Black, that definite measures of caloric are required to convert all other solids into the liquid and gaseous states:—that when a pound of steam at 212°, is mixed with 7 pounds of ice at 32°, the latter is converted into water of the same

But if caloric were a mere property or quality, how could it be taken from one body and added to another? Or if it augment the volume of other bodies, must it not itself have volume, occupy space, and therefore be a material agent?* Would it not be mere jargon to speak of the radiation, reflection, convection, and conduction of a mere quality, or immaterial property? And if caloric were only the effect of vibratory motion among the particles of ponderable matter, how could it radiate from hot bodies without the simultaneous transition of the vibrating particles? But it is certain that when iron, copper, and other metals are heated to any temperature below the point of ignition, like boiling water they give off caloric freely, without any sensible loss of ponderable matter.

It has been said, that "the material theory contains an inherent vice, by assuming the existence of a body, which has never been obtained in the sepa-

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temperature; showing that 7 × 140, or 980°, are thus transferred from the steam to the ice, and employed in melting it, without producing in it any elevation of temperature. This is what Black called the latent heat of water and steam. It has also been discovered, that a cubic inch of water at 212°, is expanded to the dimensions of a cubic foot, or about 1720-fold on passing into the gaseous state,—proving that 1719 parts by volume of steam at the same temperature, are occupied by the caloric which surrounds its particles. The same fact is still more remarkably illustrated in hydrogen gas, the volume of which is nine times greater than that of the same weight of steam, *cæteris paribus:* so that above 15,000 parts of the space occupied by hydrogen must be filled by that subtile form of matter called heat.

* We are not however to suppose, that "extension is the only essential property of matter," as maintained by Descartes.

rate form." But if caloric do not exist in a separate state while passing through a vacuum, all our reasonings about it are fallacious and unintelligible. Nor is it possible to explain, in a simple and satisfactory manner, any single one of the phenomena ascribed to it by all parties, in accordance with the hypothesis that it is identical with *motion*, which is manifestly not an agent, but merely some body in the act of moving, and always implies the existence of a mover. The most effectual method of giving a death-blow to the vibratory theory of heat, would be to show how soon it breaks down when applied to the explanation of facts.

If this theory were true, caloric ought to be generated by all impulses which throw the particles of bodies into a state of violent agitation. But such is not the fact; for if the atmosphere, the ocean, and the solid strata of the earth, were kept in a state of perpetual tremor, their temperature would not be materially altered. The advocates of the immaterial theory have never explained what causes bodies to vibrate; nor what keeps the particles of solids, liquids, and gases, at a distance from each other while quiescent, or free from vibratory motion.* And it is

* It was supposed by Bacon, that the essential nature of heat is motion, and nothing else, because it accompanies the motion of friction, percussion, combustion, ebullition, violent exercise, &c. Count Rumford was led to adopt the same opinion from the following experiments: Into a cannon weighing 113 lbs. and cast solid, he caused a hole to be bored 3·7 inches in diameter, and 7·2 inches in depth. Into this hole he introduced a blunt steel borer, that was made to rub against the bottom by horse power, with a

worthy of special notice, that *caloric is disengaged by pressure, friction, or percussion, only so long as bodies undergo condensation.* For, it has been proved by the experiments of Berthollet, Biot, and Pictet, that when pieces of gold, silver, and copper, of the same size and shape, are suddenly and forcibly struck, as when stamped in the process of coining, they were condensed, and caloric evolved, but more by the first than second blow; whereas after the third blow, when they had arrived at the limit of condensation, there was no perceptible increase of temperature. In the experiments of Berthollet on copper, the first stroke raised the temperature 17·3° F., the second 7·5°, and

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force equal to about 10,000 lbs. avoird., the cylinder being turned at the rate of thirty-two times per minute. At the expiration of thirty minutes, when the cylinder had made 960 revolutions about its axis, its temperature was found to have risen from 60° to 130° F. In another experiment, the cylinder was wrapped round with flannel to prevent the loss of heat, and inclosed in a wooden box containing 18·77 lbs. of water, which at the beginning was at the temperature of 60°. After the experiment had proceeded for an hour, it was raised to 107°,—in thirty minutes more, to 142°,—in two hours, to 178°,—and in two hours and a half, to 210°. At the close of the experiment, he found that 4145 grains of metallic dust and scales had been detached from the bottom of the cylinder by the rubbing of the borer, or above eight ounces. And as he found that the capacity, or what has been called the specific heat of the scales, was the same as that of an equal weight of solid iron, he arrived at the conclusion, that heat is not a material substance, but the mere effect of motion. (*Philosophical Transactions*, 1798.) But it will be shown hereafter, that what is called capacity or specific heat, is not a measure of the quantity in different bodies; and that this mode of estimating their latent or combined caloric is fallacious.

the third only 1·9°. (*Thomson on Heat and Electricity*, p. 339.)

In accordance with these facts, it is well known that the smith often kindles his furnace by hammering a piece of iron until it becomes red hot; and that *after he has reduced it to the limit of condensation, it becomes cold under the hammer.* I have also found, that less heat is evolved by the friction of bodies in proportion to their hardness, as when two pieces of rock-crystal are rubbed together. It is therefore evident, that caloric is not generated *de novo*, by the friction of rubbing dry sticks of wood against each other, the pressure of wire drawing, and by rubbing the hands together; but that it is merely forced out of the pores of bodies, in the same way that water is disengaged from the pores of a sponge by pressure. And it will be proved hereafter, that the caloric which is disengaged by rubbing the hands together briskly, is resupplied by the rapidly circulating blood, which obtains it by respiration.*

* Had Count Rumford been aware of the enormous amount of caloric which is locked up in a state of combination with all bodies, even when reduced to the lowest temperature that can be produced, he would not have maintained that heat is merely the effect of motion, because destitute of gravity, and because of the large amount of heat evolved by the friction of boring a cannon. In fact, Rumford himself states, that if all the heat which is required to convert a pound of ice or snow into the liquid state, were communicated to an equal weight of gold, the latter would be raised from 32° F. to the temperature of 2800°; the capacity of water for heat being 20 times greater than that of gold. Thus, the amount of caloric required to convert snow into water, without any elevation of temperature, is 140°, which, when multiplied by

That the particles of all bodies are surrounded by an elastic medium, which prevents their actual contact, is evident from their compressibility. And that this medium is caloric is proved by the facts already stated, that it augments the volume of solids, liquids, and gases, which are again reduced to their former dimensions by abstracting what was before added; and by the large amount of heat that is disengaged by friction, which is transitive pressure, or by percussion,

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20, gives 2800°; while it is probable, that between 32° and the absolute zero of ice, or any other solid body, there is a still greater amount of combined heat, had we the power of disengaging it from them. In the experiments of Berthollet, the first stroke on a piece of copper coin raised its temperature 17·3° F., the second blow 7·5°, and the third only 1·9°. It is therefore not surprising that when a blunt steel borer was made to rub against the bottom of a hole made in a cannon weighing 113 lbs., and cast solid, with a horse-power equal to 10,000 lbs., the temperature of the cylinder was raised from 60° to 130°, after it had made 960 revolutions about its axis, at the rate of 32 revolutions per minute. Such experiments prove only that caloric is disengaged from metals by forcing their particles nearer together, since the effect is not produced after they have been brought to the limit of condensation by percussion and pressure.

Among the various and contradictory opinions of Sir Humphrey Davy in regard to the nature of heat, he says, that "Caloric or the matter of heat does not exist;" that "it consists in a *vibratory* or *undulatory motion of the particles of bodies round their axes, or in a motion of particles round each other.*" But it is impossible to reconcile these views with the experiments of Berthollet, Biot, and Pictet, or with the well-known fact, (which Davy himself admits,) that when "a piece of iron is made red hot by hammering, it cannot be strongly heated a second time by the same means, unless previously introduced into a fire." (*Chemical Philosophy*, p. 95.)

which is sudden pressure; both of which cause condensation. It was estimated by Sir Isaac Newton, that the pores of gold occupy about the same space as its solid atoms; and that in water, the pores are about forty times greater than its solid particles. (*Optics*, Book ii. p. 242.) If then it be true, that all bodies are full of caloric; that it occupies 827 parts by volume of the atmosphere, and 1719 parts of steam, it must be obvious that it constitutes by far the greater proportion by bulk, of the solid globe we inhabit. And if when intimately combined with the particles of ponderable matter, its thermal properties are disguised or hidden from the senses, the same thing is true of water and the strong acids, the individual properties of which are concealed while they are in a state of chemical union with rocks, salts, &c.*

* The above facts will enable us, in some measure, to comprehend the theory of opacity and transparency, the cause of which, Sir John Herschel thinks, has never yet been satisfactorily explained. For as it is well ascertained that the particles of the atmosphere, steam, gases, water, saline and metallic solutions, like glass, and a great variety of crystalline solids, are arranged in regular series, at considerable distances from one another, the rays of light pass through them with slight interruption, giving rise to the phenomena of transmission and what is called transparency. But when the regular arrangement of the particles of ice, glass, quartz, and other crystals, is disturbed by unequal pressure, or unequal expansion by caloric, the rays of light are transmitted imperfectly: and if their symmetrical structure be broken down or deranged, as when they are reduced to powder, their power of transmitting light is so far destroyed, that they are rendered opaque. Sir Isaac Newton supposed that opacity was owing to the largeness, and transparency to the smallness, of the particles and intervening pores of bodies. (*Optics*, B. ii. p. 235.) But

Having thus proved that caloric is a material agent, I now proceed to point out its connection with the laws of motion, and the widely extended influence it exerts in all the operations of nature. The cardinal facts which connect its agency with the general theory of physics, may be reduced to the following propositions:—

1. *That the activity or moving power of all bodies is directly in proportion to the amount of caloric around their particles:—*

2. *That all molecular motions, whether centrifugal or centripetal, may be resolved into the law by which caloric repels its own particles, and attracts those of ponderable matter, with forces that vary inversely as the squares of the distance:—*

3. *That the quantity of molecular motion in the world, whether mechanical, chemical, or vital, is in proportion to the mean temperature of different latitudes,* cæteris paribus, *and diminishes from the equator to the poles:—*

4. *That the centrifugal force by which planets are impelled through their orbits, is directly in proportion to the heating power of the sun, and inversely as the squares of the distance:—*

5. *That caloric is the active principle in light, whether radiated from the sun, or generated by ordinary combustion, friction, percussion, phosphorescence, or the electric discharge:—*

6. *That every variety of electricity is convertible into caloric, and the latter again into electricity; consequently,*

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many salts, rocks, and metals, are transparent when dissolved in water and the strong acids, although their particles are much larger than those of common ink and many other bodies which are black and opaque.

that they are modifications of one and the same principle:—

7. *That the directive power of the compass-needle diminishes from the isothermal equator to the points of lowest mean temperature, which are the magnetic poles; and that all its variations correspond with the variations of terrestrial temperature:—*

8. *That the aggregate vital energy of animals, and the development of their organization, are exactly in proportion to the amount of caloric obtained by respiration, and combined with their tissues.*

That caloric is a self-active principle, might naturally be inferred from the fact, that every change in the temperature of bodies is attended with motion among their particles. It has also the power of moving from one place to another, and even through the vacuum of an air-pump, without any projectile impulse from the particles of ponderable matter; as when it radiates from hot bodies. And that it has the faculty of generating motion among the particles of other matter, would appear from all the phenomena of nature with which we are best acquainted.

For example, under the ordinary pressure of the atmosphere, and at, or a little below the temperature of 32°, the particles of water exist in the solid and apparently fixed state. But if 140° of caloric be added, their mobility is so far increased that they glide freely over one another, and assume the liquid form. If more be added, their activity is still further augmented by every degree of temperature up to the boiling point, when the whole is found to be in a state of rapid intestine motion. And if at this stage of the ex-

periment, the water be kept over a furnace until it has received about 1000° more of caloric, the boiling liquid is converted into steam, the moving force of which is exalted by every addition of this active principle, which has the power of converting all other bodies from solids into liquids, vapours, gases, and flame, or incandescent particles.

Since then it is a fact, that caloric alone gives to the quiescent particles of ponderable matter powers of motion which they do not possess without it, and that their mobility is augmented by every addition, but diminished by every abstraction of the igneous principle—it follows with all the clearness of absolute demonstration, that in the total absence of caloric, if such a condition were possible, the universal system of nature would be a motionless mass of inert and chaotic matter. It also follows, that everything in nature is composed of two descriptions of matter, the one essentially active, and the other passive; as maintained by the most distinguished sages of antiquity.

Since the time of Sir Isaac Newton, attraction and repulsion have been generally regarded as ultimate principles of action, for which no reason can be assigned.* But if it be a fact, that the elastic force of

* After referring to his theory of planetary motion, Newton observes in his Preface to the *Principia*—"Many things induce me to *suspect*, that all the rest of the phenomena of nature may depend upon *certain forces*, by which the particles of bodies, by some causes hitherto unknown, are mutually impelled toward each other in regular figures, or are repelled and recede from one another; which forces being unknown, philosophers have hitherto attempted the investigation of nature in vain." Sir H. Davy also observes, that "the various forms of matter, and the changes of these forms,

bodies is augmented by every addition, and diminished by every abstraction of caloric, it is obvious that the entire privation of it would destroy the repulsive power of their particles. And as we have seen, that without caloric, they could have no power of motion, it is evident that they could neither approximate nor recede from one another; consequently, that both attraction and repulsion are modified effects of one and the same agent. Moreover, if it can be proved that this agent is everywhere present—in the pores of bodies, as in the stellary spaces—and cannot be traced to any more comprehensive principle—it must be allowed to possess all the attributes of a primary physical cause. For, nothing can merit the title of a *vera causa*, unless it be something which has the power of moving itself, and of generating motion in other bodies.

It is equally evident, that whatever the cause of attraction and repulsion may be, it must determine all the phenomena of cohesion, chemical affinity, crystallization, elasticity,* decomposition, and recombination.

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depend upon active powers, such as gravitation, cohesion, calorific repulsion or heat, chemical attraction, and electrical attraction." (*Chemical Philosophy*, p. 67.) Dr. Arnott further states, that "attraction and repulsion are ultimate facts, which admit of no explanation in the present state of science." (*Elements of Physics.*) And Sir John Herschel adds, that "we have no means of further analyzing the phenomena of cohesion and elasticity, but must regard them, until we see reasons to the contrary, as ultimate phenomena, referable to the direct agency of an attractive and repulsive force." (*Introduction to the Study of Nat. Philosophy*, § 80.)

* If the particles of the atmosphere and other bodies were not surrounded by caloric, there could be no vibrations, (in which heat has been supposed to consist,) therefore no sound. And here it is

When I come to treat of the mode in which caloric produces opposite effects, it will be found that in certain proportions it causes the particles of ponderable matter to separate, while in other proportions it forces them to *unite*:—that the aggregate force of attraction by which it tends to unite with the particles of gross matter, holds them together, and maintains the earth in the globular form:—in short, that all the phenomena of nature may be referred to the law by which caloric repels its own particles, and attracts those of ponderable matter.

That the quantity of evaporation and rain throughout the earth is in proportion to the heating power of the sun, cæteris paribus, would seem to be a self-evident proposition. And it will be shown hereafter, from numerous scientific observations, that the annual average amount of rain within the tropics, except in desert places, is about three times greater than in the middle

worthy of notice, that the velocity with which sound is propagated through different media, is directly in proportion to their elasticity, *cæteris paribus*. For example, it travels through the atmosphere when at the temperature of 32°, at the rate of 1090 feet per second; but when at 62°, it travels 1125 feet per second, or 1275 miles per hour. It also moves at the rate of 3375 feet per second through hydrogen gas, which contains a much larger amount of caloric around its particles than the same weight of atmospheric air, or any other gas, as will be shown hereafter. In accordance with the above facts, it is well known that sound is transmitted more distinctly, and rapidly, through light and resinous, or the more combustible species of wood, than through such as are dense, less elastic, and therefore contain less of the elastic ether termed caloric. It also moves with greater velocity through water than glass, and more swiftly through either than through rocks and metals, if we make allowance for the greater density of the latter.

latitudes; and about six times greater than in the polar regions. Hence the enormous size of the tropical rivers, compared with those of the higher latitudes. For example, it has been found that the Orinoco, which drains only 400,000 square miles of territory, discharges more water into the sea than the Mississippi, which drains 1,350,000 square miles.*

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* By a reference to the mean annual depth of rain that has been observed to fall in different parts of the world, something like an adequate idea may be formed of the stupendous aggregate force exerted by caloric in the silent process of evaporation. Owing to the existing distribution of land and sea, mountains and deserts, the amount varies greatly in the same latitudes. For example, a large proportion of the area south of the United States, between lat. 10° and 30° N., consists of water; whereas nearly the whole space from N. lat. 36° to the equator, is occupied by the continent of Africa, which lies to the south and southwest of Europe. The consequence of which is, that while the annual fall of rain at Boston, New York, Philadelphia, and Ohio, is from 36 to 39 inches, and still more in the States farther south, it does not exceed 32 inches in the British Islands. And, as it diminishes from the sea to the interior of continents, the annual average is about 25 inches in western France, 22 in eastern France, 20 in central Germany, and 17 in Hungary. Moreover, as a great part of the aqueous vapour brought by the south and southwest winds from the ocean, is prevented from passing over the temperate latitudes of Europe and Asia, by the Apennines, the Alps, the Himalayas, and other mountains, precipitation is far more copious south than north of those immense barriers. It has been found that the annual fall of rain at the southern base of the Apennines is 64 inches, but only 26 inches at the northern base, and 55 inches at the southern base of the Alps, but 35 at the northern. On the southwest and northeast sides of the Ghauts, in southern India, the difference is much greater; as it is also on the western and eastern sides of the Scandinavian Mountains.

It has been calculated that the mean annual fall of rain in the

If the temperature of the whole earth were reduced to zero, there could be no fluidity of the ocean, which would be stationary as the solid frame-work of the mountains. Were it not for the heating power of the sun, there could be no contractions and expansions of the atmosphere, therefore no winds, nor fluctuations of the barometer. But in the present order of things, not an atom of the great aerial ocean is wholly quiescent for a single moment of time. Its tropical portions

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tropical zone of America is 115 inches, but only 79 inches in the same zone of Asia and Africa; while in the temperate zone of North America the estimate has been 39 inches; and in the same zone of Europe 34 inches, which is considerably more than what has been found in central Asia. But from all the observations hitherto collated, the average cannot be far from 72 inches throughout the torrid zone, which embraces an area of 79,169,410 square miles. It therefore follows by calculation, that the annual rains of the tropics would fill a basin of 89,965·2 square miles in area, and 1760 yards, or one mile, in depth. Nor can the average be far from 36 inches in the temperate zones, which embrace an area of 103,353,140 square miles. This again, if collected together, would fill a basin one mile in depth, and 58,723·4 square miles in area. In the polar regions, which embrace an area of 16,421,200 square miles, the mean annual amount of rain may be estimated at 12 inches, which if collected into one mass would fill a lake 3110 square miles in extent, and one mile in depth. By adding the above products together, it will be found that the whole amount of water that annually falls upon our planet, would fill a basin 151,723 square miles in extent, and one mile in depth. Lastly, if we divide this aggregate by the number of days in the year, it will be found that the quantity of water daily converted into vapour, wafted from the ocean through the atmosphere, and precipitated in the form of rain, snow, and hail, would make a lake of one mile in depth and 415 in area.

The proportion of sea to that of the land, is as 3·20 to 1·00.

being constantly expanded by the influence of a vertical sun, rise and give place to the denser air of colder latitudes; by which a perpetual circulation is kept up, as described in the 1st chapter of Ecclesiastes, v. 6: "The wind goeth toward the south, and turneth about unto the north: it whirleth about continually, and returneth again according to its circuits."

If the earth were of uniform surface and elevation, there would be a gradual diminution of temperature from the equator to the poles, and the winds would be as regular as the movements of the heavenly bodies. But owing to the present distribution of land and sea, mountains and valleys, plains and woods, the temperature of the globe is infinitely diversified, even in the same latitudes; by which the phenomena are rendered proportionally complex. And as the changes of weather depend chiefly on the direction of winds, they cannot be predicted with invariable accuracy, without knowing all the circumstances which modify the temperature of different and distant places. It is not therefore surprising that meteorology has never been reduced to the certainty of an exact science.

Were it possible to compute the aggregate forces of caloric in all the mechanical, chemical, and vital transformations, which are for the most part unobserved, we should be astonished at the result.* But men are

* It is in the torrid zone that nature exults in the plenitude of her powers in modifying the surface of the earth,—where the forces of the volcano, the earthquake, and of universal chemistry, are surpassed only by those which wheel the planets through their orbits. For example, we are informed by Captain Burnes, that during the Cutch earthquake of 1819, the Delta of the Indus was elevated

so accustomed to the regular course of nature, that they are less aroused by the grandeur of the sun, rising in pomp and might, filling the world with beautiful creations, and diffusing everywhere the spirit of gladness, than by a passing meteor of the night.

That the whole theory of geological dynamics is in some way immediately connected with the agency of caloric, is now generally admitted by philosophers. But the general fact to which I would here invite attention is, that *the number of volcanos and the forces they exert are in proportion to the heating power of the sun.** For example, among the 270 volcanos now in action in different parts of the earth, above 180 are confined to the tropical regions. In the island of Java alone, with a surface of 25,000 square miles, there are

about ten feet, over an area of fifty miles in length, and sixteen in breadth, in some places. We also learn from Mr. Lyell's excellent work on Geology, that during the shocks of 1822 in South America, the coast of Chili was raised about four feet, over an area of 100,000 square miles. And it is well known that similar movements are constantly taking place in different parts of the earth, or beneath the ocean.

* In every point of view, a complete theory of volcanos is of fundamental importance: for they regulate the distribution of land and sea, the magnitude and elevation of continents, the diversities of temperature in given latitudes, the character of rivers, and modify the direction of winds, which are impeded or deflected by mountain ranges. They are also the great terrestrial laboratories in which most of the precious gems are formed,—in which carbon is liquefied, and by slowly cooling under an immense pressure, assumes the crystalline form of that beautiful ornament, the diamond, which has been aptly designated as "a lump of light." Nor is it unworthy of notice, that all the richest gems and metals have been found in greatest abundance in the tropical mountains, or among the materials washed down from them by rains, rivers, and springs.

43, according to Vander Boom Mesch. (*De Incendiis Montium*, Leyden, 1826.) And there is nearly the same number in other tropical portions of the old world. Between latitudes 10° and 15°, in the Provinces of Guatimala and Nicaragua in South America, there are 21; in Peru, between latitudes 14° and 20°, there are 16; while in the tropical islands, and around the shores of the Pacific ocean, there are about 80. (See *Johnston's Physical Atlas.*)

Again; that the subterranean forces by which the dry land has been elevated from beneath the ocean, have in all past ages been in proportion to the heating power of the sun, would appear from the *relative heights of the earth in different latitudes.* Nearly the whole of tropical America, for 3000 miles in length, and several hundred in width, is one great system of mountains, separated by plains, which, within the tropics, are from 9500 to 12,800 feet above the sea. In lat. 15° N., Sorato and Illimani tower to elevations of 25,400, and 24,350 feet, according to the measurements of General Pentland. As we proceed northward toward Mexico, the loftiest peaks are those of Chuquibamba, Gualatieri, Sahama, Cotopaxi, Sierra, Antisana, and others, which vary from 19,000 to 22,000 feet, until we arrive at the table-lands of Mexico, which, between latitudes 19° and 24° N. are from 6000 to 8000 feet above the sea.

As we advance through the middle latitudes of North America, the Rocky Mountains average about 10,000 feet. And if we except St. Elias and Mount Hooker, they rarely exceed 12,000 feet. Nor do the table-lands which slope from their base exceed from

3000 to 5000: while it is well known that from latitude 60°, the elevations diminish on to the polar sea. On the other side of the equator, the highest mountains of Chili are the Aconcagua and Descabezado, which, between latitude 32·28° and 35° S. rise to elevations of 23,200, and 21,100 feet; from which they all diminish on to Patagonia, and thence to Cape Horn.*

If we turn to the old world, we shall find that there is not a single mountain chain of the first magnitude throughout the middle latitudes of Asia, Europe, New Holland, nor the islands of the sea:—that the highest plains of India are from 11,000 to 14,000 feet, while the Himalayas rise to elevations of from 23,000 to 28,000 feet, between the latitudes of 24° and 32° N.:—that the long chains of the Altai, which extend across Europe and Asia, in about the latitude of 50°, are generally from 6000 to 8000, and rarely exceed 15,000 feet:—that the mountains of western Europe also diminish in height from the Alps, the Apennines, and the Pyrenees of the south, to the Carpathians, the Dofrines, and Urals of the north, which rarely exceed 6000 feet:—that the vast plateaux of central Asia, between the Altai and the Thian-shan mountains, in lat. 45° N., are from 3000 to 5000 feet above the level of the sea; while the plains of Siberia decline gradually on to the polar ocean:—that in Greenland and Spitzbergen the average height of the mountains is about 5000 feet; while Hecla in Iceland is only 4980 feet.

* It is said that Captain C. Ross has recently discovered in S. lat. 78° a mountain 12,400 feet high. But a few such exceptions are too slight to invalidate the general law.

If the mountains of Africa are less elevated than those of southern Asia and tropical America, they are far more numerous; while two-thirds of the continent south of Sahara seem to be an enormous pile of elevated table-lands. Extending from the equator to 34° S. and 37½° N. its central plateaux are supported by an immense chain that crosses the continent from west to east; between which and its southern extremity, there are three other parallel ranges that diminish in height on to the Cape of Good Hope. The vast plains of Abyssinia and Nubia are also about 7000 feet above the ocean, and supported by innumerable mountains of still greater magnitude than those of Atlas in the west: while the eastern coast is flanked by a chain which extends, with few interruptions, from north latitude 10° to 32° S. But it is evident that the elevation and extent of table-lands, (which are in fact widely extended mountains,) afford a far more accurate measure of geological forces, than the height of a few isolated peaks.*

From the foregoing brief outline we perceive, that nearly all the highest mountains of the earth are found within 32° of the equator: and, what is still more important to observe,—*that the average elevation*

* According to Humboldt the mean estimated height of Europe is 650 feet, of N. America 750 feet, of S. America 1130 feet, and of Asia 1150 feet. That of Africa has not been ascertained, nor the relative extent of mountains and plateaux in the different zones. But M. Guyot tells us, that those of North and South America embrace one-third of its surface; those of Africa two-thirds; and the high lands of Asia five-sevenths of its area; the elevated region between the Himalaya and Altai ranges being 2400 miles long, and 1500 miles broad.

of the table-lands is about equal to that of the mountains in the middle latitudes, where, again, the table-lands are of nearly the same height as that of the polar mountains. The conclusion is therefore irresistible, that *the aggregate force by which mountains, islands, and continents have been raised, from beneath the ocean, like all the chemical transformations on the surface of our planet, is in proportion to the heating power of the sun,* cæteris paribus.

And that the same law prevails throughout the planetary system, would appear not only from analogy, but from a series of telescopic observations continued for ten years on the surface of Venus, by the celebrated Schröeter, who has estimated the height of its principal mountains as varying from 10·84 to 22·05 miles. So that after making due allowance for the uncertainty of such observations, it is probable that he has arrived at an approximation to the truth. For, as Venus is 1·40 times nearer to the sun than the earth, and as the heating power of the sun is inversely as the squares of the distance, Venus must receive more caloric than a given area of the earth, in the ratio of 1·96, or nearly as 2 to 1, because the square of 1·40 is 1·96. Nor is it unworthy of notice, that as the heating power of the sun is 6·959 times greater at Mercury than on the earth, which is 2·638 times farther from the sun, the mountains of Mercury have been estimated at 10·75 miles in height, and about eight times higher than those of the earth, compared with the magnitude of the two planets. And as Mars is 1·494 times farther from the sun than the earth, he must receive 2·232 times less caloric; which must pro-

portionally modify all the conditions of his surface. In like manner, as Jupiter is 5·157 times farther from the sun than the earth, he must receive 26·594 times less caloric. And so on to the extremity of the solar system.

But in estimating the changes which the surface of our planet has undergone during long geological epochs, we must not overlook the influence of variations in the inclination of the earth's axis, in modifying the mean temperature of different latitudes. It is generally supposed to have been demonstrated theoretically by Laplace, that the total variation of the planetary inclinations must be comprised within the narrow limits of 3°. But that, in so vast and complicated a problem as that of perturbation, geometers may have overlooked some important elements in their calculations, would seem highly probable from the limited period since which accurate observations have been made; for they admit that the disturbing influence of all the planets and their satellites upon each other is such, that millions of years are required to bring about one cycle.

But if it were wholly impossible to determine the exact amount of variation in the planetary inclinations, during the countless ages that have past, geology affords the most conclusive evidence, that at some remote period of the earth's existence, the inclination of its axis must have been far less than at present; or that the equator and poles must have been reversed. For it has been discovered that the secondary formations at Melville Island, and other parts of the polar regions, are filled with the fossil remains of plants and

animals which could have been produced only in a warm climate. Nor is it possible, that in the present inclined state of the earth's axis, tropical plants could ever have existed in these high latitudes, for the plain reason that for several months in the year they are deprived of solar light and warmth, which are essential to vegetation.

That this inclination is now actually diminishing at the rate of one minute in 126¼ years, is admitted by all astronomers. It therefore follows, that if it should go on decreasing in the same ratio, without any oscillations or retrogradations, it would wholly vanish in about 177,760 years, when there would be perpetual spring* throughout the middle latitudes, or what may be termed a vernal period of the great year. For although there would be perpetual summer at the equator, and a gradual diminution of temperature on to the highest latitudes, there would be no winter. In short, the days and nights would be everywhere of the same length, except immediately around the poles, which would be always illuminated, and there would be no variety of seasons, but an unceasing verdure would everywhere prevail. That the earth may

* In the tenth book of the sublimest song in our language, Milton represents the earth as enjoying this happy exemption from winter, before the fall of man: after which, the Creator

"Bid his angels turn askance
The poles of earth twice ten degrees and more:
* * * * * to bring in change
Of seasons to each clime; else had the spring
Perpetual smiled on earth with verdant flowers.
These changes in the heavens, though slow, produced
Like change on sea and land."

have frequently passed through such a state, is highly probable from the fact, that at the present moment the axis of Jupiter has very little if any inclination. And that this inclination has an extensive range of variation, would further appear from the fact, that in the case of Saturn it is now 28° 40′, while in that of Mars it is 30° 18′, according to Sir John Herschel. There is therefore no obvious reason why the inclination of the earth's axis should not go on augmenting until it arrives at the same angle.*

But are we not further authorized to conclude, that the equator may have gradually shifted to the middle and even the polar latitudes? This hypothesis would enable us to explain the *high and uniform temperature which prevailed throughout the northern hemisphere when the higher latitudes abounded with tropical plants and animals*,—a great physical fact which cannot be satisfactorily accounted for in accordance with the theory

* In reality, it is more in accordance with analogy to suppose that this variation may pass through an entire revolution, than that it is confined within the narrow limits of 2° or 3°. Should such a revolution go on uniformly at the rate of 48″ in a century, its completion would require a period of 2,700,000 years,—unless interrupted by a conjunction of all the planets; an event which the ancients regarded with dread, as the cause of deluges, or some other signal catastrophe. We are informed by Mr. Samuel Davis, that, according to the *Surya Siddhánta*, the oldest Hindoo work on Astronomy, the obliquity of the ecliptic was 24°, when it was written; which must therefore have been 4000 years before the 19th century. (*Asiatic Researches*, vol. ii.) From the rate at which this obliquity has diminished since the time of Tycho Brache, Sir John Herschel has adopted 48 seconds as the average in a century; or 1 minute in 126¼ years.

of Laplace. The truth is, that his mathematical reasonings were founded on the supposition that all the planets move in nearly the same plane; whereas it is now admitted by astronomers, that the orbit of Pallas is inclined to the ecliptic at an angle of 34½°, and that of two satellites of Uranus at an angle of 78° 58′. But these cosmical bodies had not been discovered when this *Système du Monde* was written; nor had Geology then taken its legitimate rank among the Sciences.

This brings us to the general theory of planetary motion. The leading facts of the solar system which connect the movements of the heavenly bodies with the agency and laws of caloric, may be reduced to the following propositions:—

1. That the sun revolves on his axis from west to east, in about twenty-five days.

2. That planets revolve around the sun, satellites around planets, and all of them upon their axes, in the same direction that the sun moves upon his axis.

3. That the heating power of the sun diminishes in proportion as the squares of the distance increase.*

* For example, as Mercury is 1·888 times nearer to the sun than Venus, he receives more caloric than Venus, in the ratio of 3·564 to one; because the square of 1·888 is 3·564. And as Mercury is 2·638 times nearer to the sun than the earth, he receives 6·959 times more caloric, or the square of 2·638. For the same reason, as Mercury is 3·944 times nearer to the sun than Mars, the latter receives 15·555 times less caloric; Ceres 25·157 times less; Jupiter, 185·259 times less on a given area; Saturn 625 times less; and Uranus 2500 times less. Or, if we take our own planet as the standard of measure, the heating power of the sun is 2·232 times greater at the earth than at Mars, because he is 1·494 times farther from the sun; 7·371 times greater than at Ceres; 26·594

4. That the centrifugal force by which planets and their satellites are impelled through their orbits diminishes in proportion as the squares of the distance from the centres of power increase.

5. That the centripetal force by which planets are impelled toward the sun, and satellites toward their primaries, diminishes in the same ratio.

6. That by the joint operation of two forces, each of which varies inversely as the squares of the distance, the celestial bodies are impelled through their orbits with velocities which vary in accordance with Kepler's third law, as shown in the following tables:

TABLE I.

	Mean distance from the sun.	*Periodic times.* d.	h.	m.	s.	*Velocities per hour.*	*Diameters.*
Mercury	36,000,000	88	0	0	0	107,100	3,200
Venus	68,000,000	224	7	0	0	79,227	7,800
Earth	95,000,000	365	6	0	0	68,098	7,912
Mars	142,000,000	687	0	0	0	54,113	4,189
Ceres	260,000,000	1681	8	0	0	40,484	......
Jupiter	490,000,000	4332	14	0	0	29,608	87,000
Saturn	900,000,000	10759	5	0	0	21,899	79,000
Uranus	1800,000,000	30686	20	0	0	15,356	35,000
Dist. of moon from the earth	237,000	27	7	43	11	2,271	2,160

times than at Jupiter; 89·737 times than at Saturn; and 358·988 times greater than at Uranus. But as the planets are impelled through their orbits by two equal and opposite forces that always counteract each other, the velocities do not diminish at the same rate as their mean distances from the sun: for while Jupiter is 5·157 times farther from the sun than the earth, his velocity is only about 2·30 times less. In like manner, although Saturn is nearly 9½ times farther from the sun than the earth, his velocity is only about three times less; and so of all the other planets, as may be readily ascertained by comparing the times and distances in the following Tables, constructed from data furnished by Sir J. Herschel. (*Treatise on Astronomy.*)

TABLE II.

SATELLITES OF JUPITER.

	Mean dist.	Periodic times. d.	h.	m.	Velocities.	Diameters.
First Satellite	263,111	1	16	28	38,929	2508
Second	418,620	3	13	14	30,860	2068
Third	667,725	7	3	43	24,433	3377
Fourth	1,174,413	16	16	32	18,423	2890

TABLE III.

SATELLITES OF SATURN.

	Mean dist.	Periodic times. d.	h.	m.	Velocities.
First Satellite	132,364	0	22	38	36,750
Second	169,850	1	8	53	32,503
Third	208,718	1	21	18	28,949
Fourth	269,350	2	17	45	25,739
Fifth	376,198	4	12	25	21,802
Sixth	872,199	15	22	41	14,320
Seventh	2,542,180	79	7	55	8,389·5

Twelve of the asteroids,* and the satellites of Uranus, have been omitted, because their elements have not yet been fully ascertained. The third column in

* The discovery of Astua, Hebe, Iris and Flora, Metis and Diana, Parthenope, Victoria, and others discovered since 1845, has augmented the number of the asteroids to fifty-two.

We are informed by Aristotle, Theophrastus, Diogenes Lantius, Cicero, and Plutarch, that the sun was recognized as the centre of our system by Pythagoras, who has been supposed by some authors to have derived this discovery from the Egyptians. But as the helisantric theory was unknown to Eratosthenes, Possidonius, and Ptolemy, (who were the most celebrated astronomers in Greece,) as it was to the ancient Hindus, Chinese, and Hebrews, there is much reason to doubt whether it was understood by any of the ancients except the admirable Pythagoras, and a small number of his disciples, who had not sufficient influence to overcome the deeply rooted prejudice of the schools. It is possible, however, that Pythagoras may have obtained a glimpse of this sublime theory from some unknown Egyptian Copernicus.

the tables was obtained by multiplying the distances by 2; which gives the diameter of the orbits. On multiplying this by 3·1416, and dividing the product by the periodic times, we get the velocities with a sufficiently near approximation to the truth for our present purpose.

After the establishment of the true solar system by Copernicus, the invention of the telescope, and the discovery of Jupiter's satellites by Galileo, the most important advance ever made in Astronomy was that of the immortal Kepler, announced in a work entitled "*Harmonice Mundi*," published in 1619. In that work, he demonstrated that "*the squares of the periodic times of any two planets are to each other, in the same proportion as the cubes of their mean distances from the sun,*" —a law which has been found equally true of satellites and their primaries,—if we except the mutual influence they exert upon each other, termed perturbation. It also led to the important discovery of Newton, that *every particle of matter in the universe attracts every other, according to the law of the inverse square of the distance;*—a law which, independent of all hypotheses in regard to the cause of motion, was one of the finest generalizations ever made in the science of Nature.*

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* In a letter to Dr. Halley, Sir Isaac Newton himself states, that the law of the inverse square of the distance was deduced from Kepler's theorems. But it was Galileo who first demonstrated, that in the descent of falling bodies, the spaces described are as the squares of the times. And Sir William Hamilton observes, "that the Newtonian theory of astronomy was but a final generalization prepared by foreign observations, and even already enounced." (*Ed. Phil. Journal*, vol. xxxv. p. 71.)

In regard to what is called Newton's first law of motion, various and opposite opinions have been entertained. But whether true or not, it was propounded by Galileo, long before the time of Newton. According to this law, as announced in the first book of the *Principia*, "every body perseveres in its state of rest or of motion, unless compelled to change that state by forces impressed thereon." On this law was founded his theory of planetary motion, as developed in the third book, in which he maintains, that when first created, the earth and heavenly bodies were projected into empty space, by the agency of a primitive impulse, communicated at various distances from their centres of gravity; by which their annual and diurnal revolutions have been ever since maintained, without any renewal of the cause.*

But in all the operations of nature with which we are best acquainted, *force is always expended in producing motion; and if not as constantly renewed, is very soon exhausted.* Nor have we the slightest proof, that motion is ever generated without the immediate agency of some active principle. The power of steam is created by the immediate agency of caloric, and ceases whenever the active principle is withdrawn. The force with which a horse-shoe magnet of soft iron holds on to the armature, is generated by the passage of an electric current through the wires which are coiled around it; but ceases the moment the current is arrested. The metallic wire that connects the ex-

* Newton observes: "That the motions of the planets may subsist an exceeding long time, it is necessary that the heavens should be void of all resisting matter."

tremities of a voltaic battery, attracts iron filings, and deflects a magnetic needle in its vicinity, so long as the electric fluid is disengaged by chemical action, but ceases whenever that action is at an end. The powers of digestion, secretion, nutrition, and muscular motion, are generated by means of an active principle which obtained from the atmosphere by respiration; but cease whenever that important function is arrested; as will be shown in subsequent parts of this work.*

* In accordance with the above views, it is observed by Sir John Herschel that, "to say matter has inertia, is only to say that the cause is expended in producing its effect, and that the same cause cannot continue to produce its effect without renewal." (*Nat. Philosophy*, sect. 234.) And it was humorously argued by the author of *Knickerbocker*, that "as the projectile force has long since ceased to operate, while its antagonist remains in undiminished potency, the world ought, in strict propriety, to tumble into the sun." Nor is this merely conjecture; it is now mathematically certain, that if the centrifugal force were suspended, the earth would reach the sun in about 64½ days, and Mercury in about 15½ days. Mr. Whewell also observes, in his *Bridgewater Treatise on Astronomy*, that "to say motion must continue the same from one instant to another, because there is nothing to stop it, seems to be taking refuge in words." But there is no one force in nature which is not counteracted by another force. It is therefore evident that Newton's first law of motion does not apply, as he originally intended, to the planetary revolutions. Mr. Whewell is equally explicit in renouncing the vacuum of space: for when treating of the luminiferous ether, he says, "it must not be merely like a material fluid poured into the vacant spaces of the material world; it must affect the physical, chemical, and vital properties of whatever it touches, and be the means of communication between planets and systems." (Book i. ch. xvii., and book ii. ch. xi.) Yet he observes, in another chapter, that "in the machinery of the universe there is, so far as we know, no material connection between the parts which act on each other." (Book ii. ch. i.)

But if it be true that caloric is perpetually radiated from the sun and fixed stars into the boundless regions of space, it must constitute an infinite ocean of ethereal essence; consequently, there can be no such thing as a vacuum, which, as Aristotle rightly observed, would destroy all motion. Nor is it less obvious, that if caloric be a self-active principle, and is everywhere present, there can be no such condition of matter as *vis inertiæ*, which literally means the power of not acting. And that a single impulse is not competent to maintain the unceasing motion of planets and satellites, is evident from Newton's own hypothesis, that they are impelled or *drawn* with an equal force at right angles to the direction of the original projection. Moreover, when Newton referred the centrifugal force to the immediate agency of the Deity, and that of gravity to an inherent property of matter, he departed from that uniformity of nature and of causation, on which all true science is founded. To be consistent, he ought to have referred all physical power to the immediate agency of the Deity, or to the inherent properties of matter. Besides, if a single impulse be capable of producing the centrifugal force, why should not a like impulse be the cause of gravity?

That the illustrious author of the *Principia* was not ultimately satisfied with the data on which his theory of planetary motion was founded, viz. the *projectile impulse, the vacuum of space,* and the *vis insita of matter,** is plain enough from what has been already said

* It might as well be said that animal motion and all the actions of life are the result of a primitive impulse, as that planets are maintained in their orbits without the continual agency of an im-

in the early part of this chapter, concerning his views of the ether. But here again he was unfortunate in his explanation of the mode in which it produces the phenomena of cohesion, capillary attraction, gravitation, &c. For he supposed that "the ether was more rare within the bodies of the sun and planets, than in the celestial spaces between them; and that its density increases perpetually in proportion as the distances increase from them, thereby causing the gravity of those great bodies toward one another, and of their parts toward each other, every body endeavouring to go from the denser parts of the medium toward the rarer." (*Optics*, Queries 20, 21.)

The failure of this hypothesis has been already exposed by Mr. Whewell, who justly observes, that the density of all radiant matter diminishes with every increase of distance from any given centre. And it will be proved hereafter, that the ether is more dense within the pores and around the particles of dense than of light bodies, in which it is more dense than in free space. On the whole, it is not very surprising that Newton's views of the ether have been generally regarded as chimerical, and insufficient to explain the leading phenomena of nature; especially as he never identified it with any known principle. And when he

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pelling principle. And if we admit that each of the eleven planets and their fourteen satellites was projected into space by a primitive impulse, is it not remarkable that the continuous force of that impulse should precisely correspond with the heating power of the sun, and be just equal to the power of gravity? The fact is, that if the sun were removed from the centre of our system, the revolutions of the different planets would cease, in spite of the primitive impulse.

referred the centripetal forces of matter to its agency, he assigned no physical cause of the centrifugal force. But if the centrifugal force of planets be directly in proportion to the radiating power of the solar orb, caloric must be the cause of this force; for the essential character of a *vera causa* is, that the effects it produces are a measure of its intensity.*

Nor is it less certain, that if the caloric which is perpetually radiated from the sun be not annihilated, it must either accumulate in the planetary spaces, and thus raise their mean temperature, or it must return to the great fountain from which it emanates. It also

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* Moreover, as the mean temperature of the earth has remained the same for long periods of time, it follows that the planets must give off by radiation the same amount of caloric they receive from the sun. This amount must depend on their superficial area, and on their distance from the sun. It therefore becomes an important question, how far it may operate in producing the centrifugal force of their satellites, just as the radiating power of the sun generates the centrifugal force of the planets themselves. At the same time it must be observed, that the motions of the satellites are subject to the direct influence of the sun; which, however, is greatly diminished by his immense distance, compared to the nearness of their primaries. For, as Sir John Herschel observes, "the greatest part of the sun's *attraction*, which is common to both, is exerted in retaining both primary and secondary in their common orbit about himself, and in preventing them from parting company; the small excess of force acting only as a disturbing power." And he states that, according to the calculations of Newton, the mean value of this excess, in the case of the moon's disturbance by the sun, does not exceed $\frac{1}{179}$ of the principal force which retains the moon in its orbit. (*Astronomy*, sect. 493.) It must also diminish, relatively, as the magnitude and distance of planets increase. Yet it is sufficient to give the orbits of their satellites the character of somewhat zigzag circles.

follows, that if the vast ethereal tide flow perpetually toward the sun, with the same force which it exerts in maintaining the centrifugal power of planets, there is no good reason why it should not be the cause of the centripetal force which maintains them in their orbits. Thus it would appear, that the projectile and gravitating forces of Sir Isaac Newton are owing to one and the same principle, which produces all the contractions and expansions, separations and combinations of the particles of ponderable matter; as will be proved in the third chapter of this, and the whole of the second book. Nor can there be a rational doubt, that in the total absence of solar radiation, all the mechanical, chemical, and vital operations of the planets would be arrested; and that *if the instellary spaces were reduced to absolute zero, there could be no motion of the heavenly bodies.*

Moreover, if it be true that there is an unceasing circulation of ethereal matter throughout the solar system, it will account for the revolution of the sun on his axis; a phenomenon which has never yet been explained in accordance with the Newtonian theory; and the knowledge of which is of fundamental importance to a right understanding of physical astronomy; as it is in the laws which regulate the actions of the sun, that we must seek for the origin of planetary motion. For example, it will be shown hereafter, that the tendency of caloric to unite with other bodies is in proportion to the quantity of matter they contain, *cæteris paribus.* Hence it is that two pounds of water will condense just twice as much steam as one pound; and that a small fire is quenched by a large quantity

of coal, with which the caloric unites, and thus arrests the process of combustion. We are therefore authorized to infer, that the aggregate force by which the ether of space tends to unite with the different bodies of the solar system, is in proportion to their mass, and inversely as the squares of the distance.*

If the sun were a perfect sphere, and not surrounded with planets, the ether would press with equal force upon all parts of his surface, and thus maintain him in a perfectly fixed state. But as he is not a perfect

* By glancing over the Tables, pp. 46–7, it will be observed that the velocity of planets round the sun does not depend upon their magnitudes, but on their distance from him, and that the same law applies to their satellites; which accords with the discovery of Galileo, that the velocity with which bodies fall to the earth is the same, whether they be large or small, dense or light, when the resistance of the atmosphere is removed. But if the distance of planets from the sun were equal, the velocity of their satellites would be in proportion to the magnitude of their primaries, and inversely as the cubes of the distance. At the present distance of the earth from the sun, the moon revolves around us at the rate of 2168 miles an hour, at the distance of 237,000 miles from the earth. But if the earth were at the place of Jupiter, and if the velocity of satellites diminish in the same ratio as that of their primaries, on receding from the sun, the velocity of the moon would be 2·303 times slower than at present, and only 941 miles an hour. It must, however, be observed, that as the volume of Jupiter is about 1300 times that of the earth, his first satellite, which is 263,111 miles from his centre, moves at the rate of 37,140 miles an hour. And if his first satellite were only 237,000 miles from his centre, (the distance of the moon from the earth,) it would move at the rate of 41,200 miles an hour, and faster than the moon, (if the earth were at the place of Jupiter,) in the ratio of nearly forty-four to one,—a difference which must therefore be owing to the difference between the magnitude of Jupiter and that of the earth.

sphere, and as the pressure of the ether upon him from every part of the solar system is modified by all the surrounding planets and satellites, it is obvious that the centripetal force of the ether must vary on different parts of his surface, so as to give him a rotary motion on his axis,—a result which may be owing in part to certain actions going on within the sun himself, and on which his radiating power depends.

The above views will also enable us to explain the diurnal revolution of planets, the elliptical form of their orbits, the inclination of their axes, and all the phenomena of the tides. In the first place, if the planets were perfectly round, and not influenced by each other, both the radiating power of the sun, and the centripetal pressure of the ether, would be the same on all parts of their surface, and they could have no rotary motion. Nor could there be any elongations of their orbits, which would be perfect circles, if the centrifugal and centripetal forces by which they are impelled were always equal and the same. But as none of the heavenly bodies are perfectly spherical, the solar radiation, like the returning pressure of the ether, must operate with unequal force on different parts of their surface, and tend to give them a rotary motion; the rapidity of which would seem to be in proportion to the difference between their equatorial and polar diameters. In the case of Jupiter, this difference amounts to 6096 miles, or in the ratio of about 107 to 100. Accordingly, he revolves upon his axis in 9h. 56m., at the rate of 27,400 miles an hour. The difference between the equatorial and polar diameters

of Saturn is still greater; being above 6700 miles, and such as to give him the appearance of a parallelogram, with the four corners rounded off deeply, but not so much as to bring it to a spheroid, as observed by Sir W. Herschel in 1805. The consequence of this deviation from the spherical form is, that although nearly 9½ times farther from the sun than the earth, his diurnal revolution is performed in 10h. 16m., and at the rate of 24,000 miles an hour. But as the equatorial diameter of the earth exceeds the polar only 24½ miles, according to Laplace, it requires 24 hours to perform its diurnal revolution, while moving round the sun with a velocity 2·30 times greater than that of Jupiter. The diurnal periods of Mercury, Venus, and Mars, are nearly the same as that of the earth; corresponding with the smallness of their deviation from the spherical form. In the case of Jupiter, this difference is as 107 to 100; whereas in the earth, it is as 299 to 298.

There is another circumstance which may have an equally important influence on the elliptical form of the planetary orbits. For example, we learn from the telescopic observations of Sir William Herschel, that all parts of the sun are not equally luminous. He thinks that one-half of the sun emits less light and heat than the other; and that if seen at a very great distance, it would appear like some of the fixed stars that have a periodical variation of lustre. At times, there may be seen on his surface spots, (one of which, on the 29th of March, 1837, occupied an area of 3,780,000,000 square miles,) which are so large as to measure 45,000 miles in linear diameter, exhibiting

the appearance of a dark, opaque, and solid ground. It therefore follows, that although the same amount of caloric is given off by the sun in any given time, different quantities are radiated from different parts of his surface, so as to augment and diminish, within certain limits, the centrifugal force of the planets, causing them to approximate the sun in certain parts of their orbits, and to recede from him in other parts, with corresponding accelerations and retardations in their annual motions, and, perhaps, variations in their mean annual temperature. On the other hand, as the centripetal pressure of the ether on each of them is modified by the disturbing influence of all those beyond, this also tends to alter the circular form of the orbits, and render them more or less elliptical. Nor is it less obvious, that the interference of the moon must cause a successive diminution of gravity or ethereal pressure upon the earth, so as to cause a corresponding elevation of the tides, which are still further elevated by the influence of the sun when in conjunction with the moon. Thus we perceive that as the mean temperature of planets, (at least of the earth,) and of the spaces between them, is uniformly the same, there must be a perpetual circulation of caloric from and to the centre of the solar system, as from and to the planets. We have also found that the heating power of the sun is just equal to the centrifugal force of planets, and an accurate equation of the gravitating force; so that whatever is true of the laws established by Kepler and Newton, must be equally true of the foregoing induction, which has the additional advantage of assigning a well-known prin-

ciple as the physical cause of the phenomena, and of thus affording a resting-place for the mind.

From all the foregoing facts and observations we are authorized to conclude, that caloric is a self-active principle which is perpetually circulating throughout the universe,—from suns to planets, and back again to the great fountains from which it emanates; in short, that it is what Homer called

"The golden everlasting chain,
Whose strong embrace holds heaven, and earth, and main."

That the movements of the heavenly bodies are in some way immediately dependent on the heating power of the sun, appears to me almost a self-evident proposition, and was so regarded by many of the ancient sages.* It was also vaguely recognized by Milton, who represents the sun as both eye and soul of this great world,—

* The agency of caloric in giving rotary motion to a globule of water or other liquid, is beautifully illustrated by some recent experiments of M. Boutigny. He found that when a small quantity of water was placed on a metallic plate heated to the temperature of 340° F. and upwards, it assumes the spheroidal state, and remains for some time poised as it were without any visible support, at a sensible distance above the surface of the metal, rolling on its axis like a little world in space. Now whatever the reason may be, that the caloric radiated from a metal heated to nearly the point of redness does not combine with the globule and convert it rapidly into steam, as at lower temperatures, there can be no doubt that caloric is the cause of its rotary motion. And if so, there is no obvious reason why solar caloric should not be the cause of planetary motion. It is supposed by M. Boutigny and other chemists, that in such cases the caloric of the heated metal is nearly all reflected by the globule, instead of combining with and converting it into steam, as it does at lower temperatures.

> "Toward which the planets
> Turn swift their various motions, or are turn'd
> By his magnetic beam, that gently warms
> The universe, and to each inward part,
> With gentle penetration, though unseen,
> Shoots invisible virtue, e'en to the deep."
>
> *Paradise Lost*, b. iii.

But we cannot expect to comprehend fully the *modus operandi* of caloric in any one class of phenomena, until we rise high enough to survey the whole field of knowledge, and to perceive the intimate connection between all its various branches. It was truly observed by Mr. Hume, that "the only expedient from which we can hope for success in our philosophical researches, is to march up directly to the capital or centre of the sciences, which being once mastered, we may everywhere else hope for an easy victory."

When I come to treat of the physiological and pathological laws of caloric, it will be found that the aggregate amount of life on our planet is in proportion to the heating power of the sun, *cæteris paribus*:—that no seed ever germinates, and no egg is ever hatched, without a due supply of warmth:—that as the thermometer rises in spring, so does the sap of plants; and as the mercury mounts up in summer, the forces of life augment, but decline in autumn, and are wholly arrested during winter:—that as the annual rings of trees correspond in thickness with the mean temperature of the growing season in the higher latitudes, and are always thickest on the side exposed to the sun,—the germination, growth, and decay of plants, constitute a natural thermometer on a grand scale. It will also be found, that organized bodies are

composed chiefly of those elements which contain the largest amount of caloric around their particles; by which they are rendered proportionally active, and endowed with the faculty of entering into vital combinations, so as to form highly complex tissues: that the vital energy of animals, the activity of their functions, and the development of their organs, are in proportion to the amount of caloric which circulates through, and is employed in combining arterial blood with the solids. A right understanding of these laws is of vastly greater importance than those of Geology, Astronomy, or even Chemistry. For until we comprehend the operations of life, health, disease, the *modus operandi* of medicines and morbific agents, the healing art can never take its appropriate rank among the exact sciences; nor be rescued from the charge of mysticism, quackery, and ignorance, of what is essential to the character of a philosophical physician. But as "the strength of a science is, like that of the old man's fagot, in the band," the candid seeker after truth is requested to suspend his judgment until he shall have carefully examined the whole of the evidence adduced in support of the author's peculiar views.

CHAPTER II.

ATOMIC CONSTITUTION OF MATTER.

"Omnia in mensura, et numero, et pondere."
Liber Sapientiæ, xi. 21.

BEFORE treating of the relative quantities of caloric in different bodies, and of the law by which it produces the opposite forces of attraction and repulsion, combination and separation, contraction and expansion, I shall present a brief outline of what is known in regard to the ultimate constitution of ponderable matter. The doctrine that everything in nature is arranged by measure, number, and weight, seems to have been recognized by the sages of India and Egypt, long before the time of Pythagoras and Democritus, who maintained that all matter is composed of exceedingly small, hard, and unchangeable atoms, that vary in magnitude; so arranged and combined as to produce an endless diversity of mineral, vegetable, and animal bodies.

The same theory was adopted by Bacon, Boyle, Newton, and many other distinguished modern philosophers, who very justly conceived that if matter were infinitely divisible, all species would be confounded. And it is obvious that if the elements did not unite in definite proportions, the laws of chemistry could not be understood, nor its results be predicted

with certainty. It is equally manifest, that if matter were infinitely divisible, a finite body must consist of an infinite number of parts, which is a contradiction. It follows, therefore, that matter must consist of ultimate atoms. In opposition to this simple and rational view of the subject, it was maintained by Boscovich, that the minutest portions of matter consist of mere *mathematical points*, without *extension or solidity, surrounded by alternate immaterial spheres of attraction and repulsion;* by one of which, the said mathematical points are drawn together, and by the other kept asunder, so as to be prevented from touching.

We are indebted to the researches of Wenzel, Bergman, and Richter, for the discovery that definite proportions of acids and alkalies are required for mutual saturation; and that many other chemical combinations take place only in fixed ratios. It was further maintained by William Higgins of Dublin, (in a work entitled "A Comparative View of the Phlogistic and Antiphlogistic Theories," published in 1789,) that all compounds are formed by the union of exceedingly minute atoms, which are surrounded by atmospheres of caloric; and that oxygen unites with nitrogen in proportions which are even multiples of the lowest. But to Dr. John Dalton of Manchester, was reserved the distinguished honour of reducing the atomic theory to a systematic form, in a work entitled "*Chemical Philosophy*," published in 1808–10,—aided by the subsequent analyses of Thomson, Berzelius, Prout, Gay-Lussac, Dulong, and many others.

The most general law of chemical affinity as announced by Dalton is, that *the constituents of ponder-*

able matter, whether simple or compound, are capable of combining with each other only in fixed or definite proportions by weight.

In a practical point of view, this law has been of the highest importance to the manufacturing chemist, independent of its connection with the whole theory of physical science.

Passing over the early and imperfect analyses of Dalton, it has been established by the united labours of the most accurate experimenters of modern times, that water is always composed of 8 parts by weight of oxygen to 1 of hydrogen; that common salt is always composed of 36 parts by weight (in round numbers) of chlorine to 23 of sodium; that carbonate of lime, whether in the form of marble, chalk, or stalactites, is invariably composed of 22 parts by weight of carbonic acid to 28 of lime, &c.

It was by thus ascertaining the relative proportions in which bodies combine chemically by weight, that Dr. Dalton was led to a perfectly simple method of deducing the relative weights of their ultimate chemical atoms. The theory assumes, that in all cases the lowest combining proportion of bodies, whether simple or compound, represents the weight of its particles; and that whenever a body combines with another in two or more proportions, the larger is an even multiple by some whole number of the smaller, as 2 to 1, 3 to 1, 4 to 1, &c.; fractional parts seldom occurring in well-ascertained cases.

By inspecting the following Table, it will be seen that the smallest combining ratio of oxygen is 8, compared with hydrogen as unity; and that when it com-

bines with other elements in larger proportions, they are 16, 24, 32, 40, or some multiple of eight. Chlorine combines with mercury in the ratio of 36, as in chloride of mercury, (calomel,) or of 72, as in the bichloride of mercury, (corrosive sublimate,) and so of carbon, hydrogen and other elements.

I have adopted the atomic numbers employed by the majority of British chemists in preference to those of Berzelius, chiefly with a view of avoiding the inconvenience of fractions. I have also chosen hydrogen as a standard of comparison for the same reason. Berzelius has selected oxygen 100·00 as a standard, on account of its great abundance, and the vast variety of combinations which it forms; while Thomson and Ure have employed oxygen as unity, by which hydrogen is rendered eight times less, or 0·125; carbon 0·75, sulphur two, mercury 25 or 12½, chlorine 4·5, and so on; both of which are unavoidably attended with fractions that are difficult to remember.

Dr. Wollaston employed the term *chemical equivalent*, and Sir Humphrey Davy *combining proportion*, to denote the atom of Dalton. I shall generally use the term atom, or particle, as indicating the smallest chemical divisions of bodies; and molecule, as a small assemblage of atoms.

Berzelius represents the different elementary bodies by the initial letters of their Latin names. Thus, O. denotes oxygen, H. hydrogen, N. nitrogen, S. sulphur, P. phosphorus, Cl. chlorine, Br. bromine, I. iodine, F. fluorine, C. carbon, Au. gold, Hg. mercury, Ag. silver, Cu. copper, Pt. platinum, Sn. tin, Pb. lead, Zn. zinc, Si. silicium, Se. selenium, As. arsenic, Fe. iron, Mn. man-

ganese, Al. aluminum, Mg. magnesium, Ca. calcium, Ba. barium, L. lithium, Na. sodium, K. potassium, (or kalium,) which are the most important.

The number of atoms in each element of a compound is indicated by figures, as in the following *formulæ.* NO_5, represents one atom of nitrogen and five of oxygen, as in nitric acid: while sulphuric acid, which is composed of three atoms of oxygen and one of sulphur, is denoted by SO_3. He has in many cases introduced symbols of still more remarkable brevity and convenience. For example, the number of oxygen atoms in a compound is designated by dots placed over the letter, which indicates the element with which it combines. Thus, the composition of water is represented by the symbol, $\dot{H}$; carbonic oxide by $\dot{C}$; carbonic acid by $\ddot{C}$; protoxide of nitrogen by $\dot{N}$; binoxide of nitrogen by $\ddot{N}$; nitrous acid by $\overset{\cdot\cdot\cdot}{N}$; and nitric acid by $\overset{\cdot\cdot\cdot\cdot\cdot}{N}$. This is a most important improvement of chemical symbols, when we reflect that oxygen enters into the composition of nearly all compound bodies.

Berzelius represents the number of sulphur atoms by commas. Thus $\overset{,}{H}$ indicates sulphuretted hydrogen; and $\overset{,,}{H}$, bisulphuretted hydrogen, &c. He also denotes various compounds by the initial letters of their names. Aq. represents water; Cy. cyanogen; Ni. nitrate of potass; Am. ammonia, &c. It is sometimes convenient to denote two atoms of an element by a dash under its symbol. Thus $\underline{\overset{\cdot\cdot\cdot}{Fe}}$, denotes two atoms of iron and three of oxygen, as in the peroxide of iron.

TABLE OF ATOMIC WEIGHTS,

AND OF THE SYMBOLS BY WHICH THEY ARE REPRESENTED.

Parts by weight.		Parts by weight.		
8	Oxyg. combine with	1 H. to form	$\dot{H}$	9 parts by weight of water.
16	O_2	1 H	$\ddot{H}$	17 Binoxide of hydrogen.
8	O	6 C	$\dot{C}$	14 Carbonic oxide.
16	O_2	6 C	$\ddot{C}$	22 Carbonic acid.
16	O_2	16 S	$\ddot{S}$	32 Sulphurous acid.
24	O_3	16 S	$\dddot{S}$	40 Sulphuric acid.
8	O	14 N	$\dot{N}$	22 Protoxide of nitrogen.
16	O_2	14 N	$\ddot{N}$	30 Binoxide of do.
24	O_3	14 N	$\dddot{N}$	38 Hyponitrous acid.
32	O_4	14 N	$\ddddot{N}$	46 Nitrous do.
40	O_5	14 N	$\overset{\cdot\cdot\cdot\cdot\cdot}{N}$	54 Nitric do.
8	O	36 Cl	$\dot{Cl}$	44 Hypochlorous acid.
32	O_4	36 Cl	$\ddddot{Cl}$	68 Hypochloric do.
40	O_5	36 Cl	$\overset{\cdot\cdot\cdot\cdot\cdot}{Cl}$	76 Chloric acid.
8	O	40 K	$\dot{K}$	48 Potassa.
8	O	24 Na	$\dot{Na}$	32 Soda.
8	O	20 Ca	$\dot{Ca}$	28 Lime.
24	O_3	8 Si	$\dddot{Si}$	32 Silex, silicic acid.
8	O	64 Cu	$\dot{Cu}$	72 Protoxide of copper.
16	O_2	64 Cu	$\ddot{Cu}$	80 Binoxide of do.
8	O	200 Hg	$\dot{Hg}$	208 Protoxide of mercury.
16	O_2	200 Hg	$\ddot{Hg}$	216 Binoxide of do.
8	O	110 Ag	$\dot{Ag}$	118 Protoxide of silver.
24	O_3	32 P	$\dddot{P}$	56 Phosphorous acid.
8	O	28 Mn	$\dot{Mn}$	36 Protoxide of manganese.
8	O	28 Fe	$\dot{Fe}$	36 Protoxide of iron.
24	O_3	56 Fe_2	$\underline{\dddot{Fe}}$	80 Peroxide of iron.
8	O	12 Mg	$\dot{Mg}$	20 Magnesia.

Parts by weight.		Parts by weight.				
8	O	14	Al	$\underline{\dddot{Al}}$	22	Alumina.
24	O_3	12	C	$\overset{\therefore}{C_2}$	36	Oxalic acid.
36	Cl	1	H	HCl	37	Hydrochloric acid.
126	I	1	H	HI	127	Hydriodic acid.
16	S	1	H	$\overset{,}{H}$	17	Sulphuretted hydrogen.
32	S_2	1	H	$\overset{,,}{H}$	33	Bisulphuretted hydrogen.
6	C	2	H_2	CH_2	8	Light carburetted do.
12	C_2	2	H_2	C_2H_2	14	Olefiant gas.
12	C_2	14	N	C_2N	26	Cyanogen.
36	Cl	24	Na	NaCl	60	Chloride of sodium.
24	C_4	4	H	C_4H_4	28	Etherine (En).
36	C_6	3	H	C_6H_3	39	Bicarburet of hydrogen.
36	C_6	5	H	C_6H_5	41	Naphtha.
60	C_{10}	4	H	$C_{10}H_4$	64	Naphthalin.
90	C_{15}	4	H	$C_{15}H_4$	94	Paranapthalin.
14	N	3	H	NH_3	17	Ammonia.
8	O	100	Au	AuO	108	Protoxide of gold.
8	O	104	Pb	PbO	112	Protoxide of lead.
8	O	96	Pt	PtO	104	Protoxide of platinum.
24	O	72	Bi	$\dddot{Bi}$	80	Oxide of bismuth.
26	Cy	1	H	HCy	27	Hydrocyanic acid.
26	Cy	8	O	$\dot{Cy}$	34	Cyanic acid.
26	Cy	40	$\overset{\therefore}{S}$	$Cy\overset{\therefore}{S}$	66	Sulphocyanic acid.
26	Cy	36	Cl	CyCl	72	Chlorocyanic acid.
14	C_2H_2	9	Aq	$C_4H_5\ddot{H}$	23	Alcohol.
28	C_4H_4	9	Aq	$C_4H_4\dot{H}$	37	Ether.
22	$\ddot{C}$	17	NH_3	$NH_3\ddot{C}$	39	Carbonate of ammonia.
44	$\ddot{C}_2$	48	$\dot{K}$	$\dot{K}\ddot{C}_2$	92	Bicarb. of potassa.
54	$\overset{\therefore\cdot}{N}$	48	$\dot{K}$	$\dot{K}\overset{\therefore\cdot}{N}$	102	Nitrate of potassa.
37	ClH	17	NH_3	NH_3HCl	54	Muriate of ammonia.

Parts by weight.	Parts by weight.		
37 ClH	28 En	EnHCl	65 Muriatic ether.
40 $\dddot{S}$	32 $\dot{Na}$	$\dot{Na}\dddot{S}$	72 Sulphate of soda.
40 $\dddot{S}$	20 $\dot{Mg}$	$\dot{Mg}\dddot{S}$	60 Sulphate of magnesia.

The lowest numbers in the first two columns of the above table down to oxide of bismuth, represent the atomic weights of simple bodies, or multiples of them; while the numbers of the third column, including all those from hydrocyanic acid in the first and second columns, denote the weights of compound particles or molecules.

The recent progress of chemical science has led to the discovery of some apparent exceptions to the law of multiples. The following examples have been indicated by Dr. Turner. The peroxide of iron is composed of 12 parts oxygen to 28 of iron. Oxygen combines with manganese in the same ratio, forming a sesquioxide, from the Latin word *sesqui, one and a half.*

This difficulty has been evaded by supposing that two equivalents or atoms of one substance unite with three, five, or more atoms of another—that if one atom of iron unite with one of oxygen, and another compound be formed of two atoms of iron to three of oxygen, the latter would be in the proportions of one and one-and-a-half, and so of other like cases.

When one atom of oxygen unites with two of lead, they form a ternary atom of what is termed a dinoxide, or a suboxide. Dr. Turner lays it down as a general rule, that when a metal forms two oxides, the oxygen of which is in the ratio of one to one-and-a-half, the first is usually the protoxide, and the second a compound of two atoms or equivalents of the metal to

three of oxygen, as in the oxides of iron, nickel and chromium.

It is highly probable, that a more accurate and refined mode of analysis will prove hereafter that several of the present atomic numbers do not represent the true weights of the atoms. But it is also probable, that in nearly all cases where this is not so, they represent either multiples or submultiples of them.

There are other exceptions to the law, that all bodies combine chemically in fixed or definite proportions by weight. Many of the metals unite with each other in all proportions when converted into the liquid state by heat, or electricity, forming alloys.

Water combines with alcohol, and with the strong acids in unlimited proportions; and it will be shown, further on, that the ratios in which sugar, numerous salts, oily, resinous and gelatinous substances, unite with water by chemical solution, are determined by the temperature of the water, solubility of the bodies, &c. But in all such cases, the affinity is comparatively weak, and the changes of properties consequent on combination inconsiderable.

THEORY OF VOLUMES.

In the year 1805, Gay-Lussac and Humboldt proved by numerous experiments, that water is always composed of two measures by volume of hydrogen to one of oxygen, as had been previously shown by Higgins. By following up the investigation, Gay-Lussac found, that many other gases, both simple and compound,

unite with each other in very simple ratios by volume; that one volume of A unites with one, two, three, or more volumes of B; and that the bulk of the resulting compounds always bears a very simple and definite ratio to that of its constituents, or to that of one of them.*

This law has been extended by Dr. Prout and others to vapours, and even to the supposed vapours of bodies which do not exist in the elastic form, except when united with the permanent gases. For example, if carbon be burnt in 100 cubic inches of oxygen gas, (the weight of which is 34·60 grains,) an equal volume of carbonic acid is formed, (which weighs 47·26 grains;) showing that 12·66 grains of carbon have been dissolved and chemically united with 100 cubic inches of oxygen, and thus converted into the elastic state; and that two atoms of oxygen have united chemically with one of carbon. In this way it was found, that the specific gravity of carbon vapour is ·416, compared with oxygen 1·111, as determined experimentally by Dr. Thomson.† It was also found that

* *Mémoires D'Arcueil*, 1809, tome ii.

† Mitscherlich has maintained recently, that the specific gravity of carbon vapour is double the estimate of Prout. He observes, that as it cannot be determined by direct experiment, it ought to be deduced from analogy—for example, if carbonic acid consisted of equal volumes of carbon vapour and oxygen, he maintains that they ought to combine without any condensation, because in all other cases, when equal volumes of gaseous bodies unite chemically, there is no contraction, as in binoxide of nitrogen, hydrochloric acid, hydriodic acid, &c. He thinks that condensation never takes place, unless the combining volumes are unequal; therefore, that carbonic acid is composed of one volume of oxygen to half a volume of carbon vapour, (the specific gravity of which

when sulphur is chemically combined with oxygen by combustion, an equal volume of sulphurous acid is formed, the specific gravity of which is 2·222, or just double that of oxygen: therefore it is evident, that 100 cubic inches of sulphur vapour, as it exists in sulphurous acid, are of the same weight as 100 cubic inches of oxygen. Such facts led to a new mode of ascertaining the atomic weight of bodies, and shed much additional light on the ultimate constitution of matter. For example, if sulphurous acid be composed of two atoms of oxygen to one of sulphur, it follows, that the atom of sulphur must be just 16 times that of hydrogen, and double that of oxygen.

By pursuing this method of investigation, Dr. Thomson arrived at the conclusion, that carbon, oxygen and sulphur, are even multiples of hydrogen without fractions; (*Records of Science*, March, 1836;) whereas Berzelius makes the atomic weight of carbon 0·76438; that of sulphur 2·01165; and sulphurous acid 4·01165, compared with oxygen 100.

Without pretending to decide which of these illustrious experimenters has approximated most nearly to the truth, it would appear from all the lights of modern analysis, that when the atomic numbers shall have been ascertained with perfect accuracy, they will be found to constitute very simple ratios. It is obvious, that if the atomic weight of carbon is six times that of hydrogen, oxygen eight, and sulphur 16, the

would be ·832, instead of ·416, or 12 times that of hydrogen.) But it is not very material whether we regard the specific gravity of carbon vapour as six or twelve times that of hydrogen, as either number is in accordance with the law of multiple ratios.

above and many other equivalent numbers of Berzelius cannot be correct; which is also the case with those of Dr. Turner, who has adopted most of them. Whether this be true or not, the simplity of the atomic theory, as proposed by Dalton, and improved by later chemists, has been greatly diminished by the number of decimals which Berzelius has affixed to his atomic weights. I concur most fully with Professor Forbes, in the hope that philosophers may dismiss that superfluity of decimal places which has been recently introduced into several branches of physical science. They have already tended to shake the confidence of some, as to the soundness of the atomic theory.

The important discovery of Gay-Lussac has been so far extended and verified by the united researches of modern chemists, that it may be regarded as an established law, that all gaseous bodies combine with each other in definite proportions by volume, and in accordance with the law of multiples.

The following table will show the connection between the specific gravity of gaseous bodies and their atomic weights. The first column of figures represents their specific gravities, compared with common air as a standard, deduced from the experiments of Thomson, Prout, Berzelius, Dulong, Gay-Lussac, Ure, Dumas and Mitscherlich, under the ordinary pressure of the atmosphere, and at the temperature of 60° F. with the exception of phosphorus, sulphur, arsenic, and such other bodies as require higher temperatures to convert them into the gaseous state. The second column exhibits the number of grains in 100 cubic inches; while the third column gives the relation of

their specific gravity to that of hydrogen as unity; and is obtained by dividing the numbers in the first column by the specific gravity of hydrogen.

Gases and vapours.	Specific gravities.		No. of grains in 100 cubic inches.	Sp. gr. compared with hydrogen.
Atmospheric air	1·000		31·01	15
Chlorine	2·500	Cl.	76·20	36
Iodine vapour	8·716	I.	265·76	126
Bromine do.	5·555	Br	169·29	80
Carbon vapour	·416	C	12·68	6
Carburetted hydrogen	·555	CH_2	17·80	8
Olefiant gas	·981	C_2H_2	29·90	14
Etherine vapour	1·963	C_4H_4	61·13	28
Carbonic oxide	·972	CO or $\dot{C}$	29·62	14
Carbonic acid	1·527	$\ddot{C}$	47·26	22
Aqueous vapour	·625	$\dot{H}$	19·05	9
Alcohol vapour	1·620	$C_4H_6O_2$	49·37	23
Ether do.	2·570	C_4H_5O	79·67	37
Cyanogen	1·815	C_2N	56·47	26
Sulphurous acid	2·222	$\ddot{S}$	67·72	32
Sulphuric acid	2·777	$\dddot{S}$	84·72	40
Protoxide of nitrogen	1·527	$\dot{N}$	47·26	22
Nitrous acid	3·19	$\ddddot{N}$	98·80	46
Nitric do.	3·75	$\overset{\cdot\cdot\cdot\cdot\cdot}{N}$	116·14	64
Hydrogen gas	0·0690	H	2·13	1
Phosphuretted hydrogen	1·185	PH	36·74	17
Nitrogen gas	·972	N	30·16	14
Ammonia	·590	NH_3	18·19	8·5
Hydrochloric acid	1·270	HCl	39·36	18·5
Hydrocyanic do.	·942	C_2NH	29·30	13·5
Binoxide of nitrogen	1·041	$\ddot{N}$	32·13	15

Gases and vapours.	Specific gravities.	No. of grains in 100 cubic inches.	Sp. gr. compared with hydrogen.
Hydriodic acid	4·409	HI	63·5
Hydrobromic acid	2·812	HBr	40·5
Mercury vapour	6·944	Hg	100
Protochloride of mercury	8·204	HgCl	118·5
Bichloride of do.	9·431	$HgCl_2$	136
Bromide of do.	9·665	HgBr	140
Oxygen	1·111	O 34·60	16
Phosphorous vapour	4·444	P	64
Arsenic vapour	10·625	As	150
Sulphur do.	6·666	S	96

By comparing the numbers in the third column of the table, down to nitrogen, with the atomic weights in the preceding table, page 67, it will be found that they are identical; or, that the specific gravity of the gases and vapours in the upper department of the table corresponds with their atomic weights, as deduced from the analyses of compound bodies. From which it follows, that equal volumes contain equal numbers of atoms.

This however is not the case with the next class of gaseous bodies; for it will be observed, that from ammonia down to bromide of mercury, the atomic weights in the third column are just half of what they ought to be, were the atom and the volume the same; that is, allowing the atomic weights in the first table to be the true ones.

It will also be observed, that the specific gravity of oxygen is 16 times that of hydrogen, while its atomic weight is only eight; showing that its specific gravity

is double its atomic weight as exhibited in the first table. The difference is still greater between the specific gravity of phosphorous vapour and its atomic weight, in the ratio of two to one, or of 64 to 32. The same is true of arsenic vapour, its specific gravity being 150 times that of hydrogen, and its atomic weight only 75; while the specific gravity of sulphur vapour is six times its atomic weight, the former being 96, and the latter 16.

The following table will illustrate the nature and importance of the facts on which the theory of volumes is founded, and their connection with the atomic constitution of matter:—

Vols. or cubic inches.		Cubic inches.			Vols.	
200	H. combine	100	O. to form	Aq.	200	of Aqueous vapour.
300	H. do.	100	N. to form	Am.	200	Ammonia.
200	H. do.	100	C. vapour	CH_2	100	Light Carbur. hyd.
200	H. do.	200	C. do.	C_2H_2	100	Olefiant gas.
400	H. do.	400	C. do.	En.	100	Etherine vapour.
300	H. do.	600	C. do.	C_6H_3	100	Bicarburet of hydr.
500	H. do.	600	C. do.	C_6H_5	100	Naptha vapour.
1000	Car. vapour	400	H	$C_{10}H_4$	100	Napthalin vapour.
1500	C. do.	400	H	$C_{15}H_4$	100	Paranapthalin do.
200	Nit. vapour	100	Oxygen	NO	200	Protoxide of nitr.
200	N. do.	300	O	$\overset{\therefore}{N}$	200	Hyponitrous acid.
200	N. do.	400	O	$\overset{::}{N}$	200	Nitrous acid.
200	N. do.	500	O	$\overset{.\cdot.\cdot.}{N}$	200	Nitric acid.
100	C. vapour do	200	O	$\ddot{C}$	200	Carbonic acid.
200	C. do. do	100	N	C_2N	200	Cyanogen.
400	Car. oxide	400	H	$\dot{C}_4H_4$		Hydrous acetic acid.
100	Olefiant gas	100	Aq. vap	$C_4H_5O_2$	100	Alcohol vapour.
200	do.	100	Aq. do.	C_4H_5O	100	Ethereal vapour.

Vols. or cubic inches.	Cubic inches.		Vols.	
100 Chlorine do.	100 H	HCl	200	Hydrochloric acid.
100 C. vapour	100 O	$\dot{C}$	200	Carbonic oxide.
100 I do.	100 H	HI	200	Hydriodic acid.
100 Cy	100 H	HCy	200	Hydrocyanic acid.
100 Cy	100 Cl	CyCl	200	Cyanuret of chlorine.
100 Cy	100 I	CyI	200	Cyanuret of iodine.
200 N	200 O	$\ddot{N}$	400	Binoxide of nitr.
25 P	100 H	HP	100	Phosphuretted hyd.
16 Sulphur vap.	100 H	HS	100	Sulphuretted do.
16 S. do.	200 O	$\ddot{S}$	200	Sulphurous acid.
16 S. do.	300 O	$\dddot{S}$	200	Sulphuric acid.

By glancing over the above table, we perceive that the aggregate volume of the eighteen first gases and vapours, down to ether, is reduced during chemical combination from 3 to 2, 4 to 2, 3 to 1, 4 to 1, (as in olefiant gas;) from 8 to 1, as in etherine; from 9 to 1, in Faraday's bicarburet of hydrogen; from 11 to 1, in naptha vapour; from 14 and 19 to 1, as in napthalin and paranapthalin; in all of which, the specific gravity and atomic weight coincide.

The next class of gases and vapours, in the second department of the table, unite chemically without any change of volume, such as chlorine and hydrogen, to form hydrochloric acid gas, the specific gravity of which is a mean of its constituents; and so of the other six gases and vapours, including binoxide of nitrogen; in all of which the specific gravity represents only one-half of their atomic weights.

It will also be observed, that the volume of phosphorous vapour is augmented from 25 to 100, on uniting

with hydrogen, and that of sulphur from 16 to 100, as in sulphuretted hydrogen, sulphurous acid, &c.

Here is a most important series of phenomena that have never been explained:—1. Why the specific gravity of gaseous bodies does not always correspond with their atomic weights, except in accordance with the law of multiple or submultiple ratios:—2. Why many gases unite chemically with contraction of volume and diminution of elastic force:—3. others without contraction:—4. and some with expansion of volume, as the vapours of sulphur, phosphorus, &c.

It will be shown in the next chapter, that all the phenomena of contraction, expansion, and the elastic force of gaseous bodies, depend on their relations to caloric, which surrounds every atom of ponderable matter, and, by its transition from one body to another, determines all the chemical or physical changes which they undergo; that the elastic force of hydrogen, oxygen and nitrogen, (which depends on the relative proportions of caloric and ponderable matter of which they are composed,) is so great, that no degree of force, except that of chemical attraction, has been adequate to condense them perfectly into the liquid form; but that on uniting chemically with each other, and with carbon, phosphorus, sulphur and various other bodies, they are deprived of their elastic force, and in many cases without any disengagement of caloric.

The following observations will show at once how chemical affinity modifies the specific gravity and elastic force of gases. It has been seen that the specific gravity of chlorine is 36 times that of hydrogen. Its

elastic force is also small, as it may be condensed by a pressure equal to four atmospheres, or even by cold without pressure. But when 100 cubic inches of chlorine unite chemically with 100 cubic inches of hydrogen, (the elastic force of which is immense,) they form 200 cubic inches of hydrochloric acid gas, the elastic force of which is equal to the pressure of 40 atmospheres at the temperature of 50°. During this combination, the larger atoms of chlorine receive from those of hydrogen a definite ratio of caloric, by which the elasticity of the hydrogen is diminished, and that of the chlorine increased. At the same time, the atoms of chlorine are removed farther from each other, causing an alteration of specific gravity in the resulting compound. In like manner, when one volume of iodine vapour, the specific gravity of which is 8·75, unites chemically with an equal volume of hydrogen, the specific gravity of the resulting compound is diminished to 4·385; and so of the rest, together with many other like combinations not set down in the table.

The volume of phosphorous, arsenic and sulphur vapours is still further augmented on uniting with hydrogen and other permanent gases. The specific gravity of these vapours, as deduced from the experiments of Dumas and Mitscherlich, (who converted them into the gaseous state by heat,) is 4·444, 10·625, and 6·666, (*see table, page* 74;) but when phosphorous vapour unites with hydrogen, its volume is augmented fourfold; that is, from 25 to 100, as in phosphuretted hydrogen. Sulphur vapour is expanded still more on uniting with hydrogen, viz. from 16 to 100, as in sulphuretted hydrogen, as before stated.

Now it must be remembered that the vapours of phosphorus, sulphur, mercury and arsenic, have little or no elasticity, unless at high temperatures; from which it follows, that their volume and elastic force are augmented on uniting with hydrogen, by acquiring from it a sufficient amount of caloric to produce the effect. These views will be more fully expanded when I come to treat of the attractive and repulsive forces of caloric.

When thus investigated in connection with the cause which moves atoms, and the law by which they are united and separated, the atomic theory embraces the whole science of nature. But until the mutual relations of ethereal and ponderable matter shall be better understood, the theory of atoms, and consequently that of chemistry, must remain involved in profound obscurity; a lifeless mass of phenomena, for which no satisfactory reason can be assigned.

In regard to several bodies termed elementary, chemists have not yet been able to determine whether we have obtained their true atomic weights, or only multiples or submultiples of them. At one time, it was supposed by Ampère and Dumas, that equal volumes of all gases and vapours, simple or compound, contain exactly the same number of atoms. In order to sustain this hypothesis, so beautiful from its simplicity, Dumas imagined that when chlorine unites chemically with hydrogen to form hydrochloric acid gas, their atoms undergo a division, by which two atoms of the acid are formed out of one of each of its elements. It is needless to insist, that these hypotheses have not been found in accordance with established facts.

That equal volumes of all gases contain equal numbers of atoms was inferred, first, from the circumstance that all gaseous bodies are equally expanded by the same additions of caloric, the pressure being equal: and secondly, from the supposed fact, (which has been termed the law of Mariotte,) that the volume of any gas whatsoever, diminishes in proportion to the pressure exerted upon it, the temperature being equal. It was maintained, that if the number of atoms in each gas were not the same, the diminution of volume under the same pressure ought also to vary. Recent experiments performed by Œrsted and Despretz, have proved that this is actually the case; that the volume of sulphurous acid, cyanogen, ammonia and sulphuretted hydrogen, diminishes much more rapidly under an equally increasing pressure, than oxygen and nitrogen, as in common air; consequently, that the law of Mariotte is not true when applied to gases indiscriminately; but only to such as have the same degree of elastic force. Despretz regards the above deviation from the law of Mariotte, as referable to some *unknown law which regulates the constitution of gases.*

When I come to treat of the causes which modify the elastic force of gases, it will be shown that their volume and compressibility are determined by their relations to caloric, and not by the number of atoms in a given volume.

Berzelius maintains in a recent work, entitled *Des Proportions Chimiques*, that the atomic weights of simple bodies are represented by their specific gravity in the gaseous state: from which it would follow, that the atomic weight of hydrogen is one-sixteenth that of

oxygen, instead of one-eighth, corresponding with the difference between their specific gravities. And as it was found that water is always composed of two volumes of hydrogen to one of oxygen, it was inferred by Davy, Berzelius, Prout and others, that water is compounded of two atoms hydrogen to one of oxygen.

In like manner, when it was found that the protoxide of nitrogen is composed of two volumes nitrogen and one of oxygen, it was inferred that it is a compound of two atoms nitrogen to one of oxygen. In accordance with this view, Berzelius and many of the continental chemists regard the *hydrogen atom* of Dalton, and the *nitrogen atom* of Thomson, Turner, Brande and other British authors, as double atoms, or multiples of their real weights. But if it be true, that the only combining proportions on which we can depend, are such as the most accurate experimenters have found them to enter by weight into the composition of compound bodies, we are not authorized to adopt the numbers of Berzelius, until verified by new and more accurate methods of analysis. At the same time, I am free to confess, that the great degree of elastic force in nitrogen, favours the opinion of Berzelius, that its atomic weight is seven, compared with hydrogen, instead of 14. It cannot, however, be supported on the ground that equal volumes of gases and vapours contain the same numbers of atoms; for it is manifest, that while the atomic weight of ammonia is 17 times that of hydrogen, its specific gravity is only 8·5; that the atomic weight of hydrochloric acid is 37, but its specific gravity only 18·5, and so of various other gases. It is also evident, that whenever the specific

gravity of gases does not correspond with their atomic weights, they vary according to the law of multiples or submultiples, which renders the theory of volumes nearly as simple as if the atom and the volume were always the same.

It is exceedingly difficult, if not wholly impossible, to explain the foregoing phenomena of chemical combinations, without adopting the theory of Newton, Higgins and Dalton, that the elements of ponderable matter are composed of ultimate atoms, which, however minute they may be, must have both *extension* and *weight*. If they were *mere mathematical points*, or *mere centres of force*, *without extension*, as maintained by Leibnitz, Boscovich, Kant, Ecloy and Faraday, they could not possibly form extended and massy aggregates.* That ponderable matter consists of incalculably small particles or atoms, is evident from all the phenomena of solution, the diffusion of odours, and the minuteness of organized animalcules. According to the observations of Ehrenberg, a single grain of silex has been found to contain 187,000,000 animalcules in the fossil state. Verily, the revelations of Science require faith as well as reason.

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* In a paper published in the *London and Edinburgh Phil. Magazine*, for 1845, Faraday maintains that "the modern theory of atoms is at best an assumption." "To my mind," says he, "the nucleus vanishes, and the substance consists of the powers." He adds: "gravitation is a certain property of matter, dependent on a certain force, and it is this *force* which constitutes the *matter*." Moreover, as Kant resolved heat, electricity and light, into the *forces* of attraction and repulsion, Faraday has further resolved them into the *polarity of forces*.

The phenomena of crystallization are not less astonishing. When a drop of solution of muriate of ammonia is magnified by an oxy-hydrogen microscope, it is seen to shoot into many hundred thousand small crystals, (each of which must contain at least as many ultimate atoms,) which coalesce into one symmetrical solid crystal; yet are they all governed and arranged by *number*, *measure* and *weight*. An ultimate particle of lead, which is 104 times greater than an atom of hydrogen, is estimated by Dr. Thomson as only $\frac{1}{310,000,000,000}$th of a grain. Yet, if the *igneous ether* which surrounds these molecules be a material agent, its particles must be inconceivably smaller. We can no more measure the ultimate minuteness of this spiritual and fiery essence than we can comprehend the infinitude of space and duration. We are less amazed on contemplating the vast cycles of geology and astronomy, than by attempting to follow nature in her smallest proportions. We know not the absolute weights of atoms, but we know from the preceding facts, especially those on which the law of multiples is founded, that they vary in size. We know not the forms of ultimate atoms, nor whether they are all of the same density; but as all bodies in the liquid state are disposed to assume a round form, we may conclude that they are spherical, and that the various forms of crystalline bodies are determined by the modes in which their particles are grouped and arranged.

RELATIVE QUANTITIES OF CALORIC IN DIFFERENT BODIES.

This is one of the most difficult problems in Physical Science, the very elements of which have yet to be unfolded. If it be true, that the whole material world is composed of particles or atoms which vary in size, and that they are surrounded by an active and ethereal principle, which is immediately connected with all their properties and changes, it is obviously an object of primary importance to ascertain the relative proportions of each, and the laws of their operation upon each other. Without hoping fully to develope a subject which has hitherto baffled so many able men, I shall endeavour to show, that the methods which have been employed for the purpose of estimating the constituent caloric of bodies are fallacious; the application of which, to the phenomena of combustion, respiration, evaporation and solution, has been a constant source of error.

It has been known ever since the time of Dr. Black, that different quantities of caloric are required to produce the same temperature, in equal weights or volumes of different bodies; that one pound of water requires about double the quantity of caloric to raise its temperature 50° or 100°, that one pound of oil does; and that on cooling an equal number of degrees, water gives out twice as much caloric as an equal weight of oil: from which it was inferred, that the same difference existed between the latent caloric of oil and water at all temperatures, down to their absolute zeros; in other words, that the whole amount of caloric in water is double that of oil.

This difference of capacity for caloric, as it was termed by Dr. Black and his disciples, which was found to exist between all other bodies, has been regarded by Crawford, Kirwan, Lavoisier and Laplace, Leslie and Dalton, as a measure of the relative quantities of caloric which is chemically combined with them, and has been generally termed *specific heat*. But it is now universally conceded, that the whole subject is involved in profound obscurity, and that nearly all the experiments connected with specific heat are at variance with each other, which alone is a sufficient proof that the truth has not yet been fully ascertained.

According to the above mode of deducing the amount of caloric in bodies, water should contain more than an equal weight of any other known liquid or solid, as it gives out a larger quantity on cooling an equal number of degrees. If *capacity* or *specific heat* were a true criterion of what they contain, the latent caloric of ether, alcohol, oils, wood, coal, and all those bodies which are known to be the most combustible, would be comparatively low. But this idea is refuted by the amount of hydrogen that enters into the composition of such bodies; and by the fact that hydrogen gives out more caloric, during combustion, than an equal weight of any other known substance. Ever since the first discovery of hydrogen, it has been regarded as an exceedingly igneous substance. The older chemists termed it inflammable air. At one time, Kirwan maintained that it was identical with the phlogiston of Stahl, which was in reality the undiscovered latent heat of Black.

These vague hypotheses were superseded by the more definite views of the celebrated Lavoisier, who proved that hydrogen is composed of a ponderable base, united with an igneous fluid, which he termed caloric, and which may be separated from each other by chemical action.

According to the experiments of Dr. Dalton, caloric enough is given out during the combustion of one pound of hydrogen gas to melt 320 lbs. of ice. According to Crawford, 480 lbs. of ice are melted by the heat given out during the combustion of one pound of hydrogen; which Dr. Thomson thinks is about as far beyond the truth as Dalton's estimate falls short; and that about 400 pounds may be regarded as the mean quantity of ice that will be melted during the combustion of one pound of hydrogen. If then we admit with Dr. Black, that 140° of caloric are required to melt one pound of ice, 56,000° of heat must be given out during the combustion of one pound of hydrogen.

It must however be observed, that during the process, two volumes of hydrogen combine chemically with one of oxygen; or that one atom of oxygen combines with one of hydrogen; and as the atomic weight of oxygen is eight times that of hydrogen, eight pounds of oxygen must unite with one of hydrogen, making nine pounds of water. From which it is evident, that a certain proportion of the caloric disengaged, is afforded by the oxygen; for we find that the volume and elastic force of both gases are destroyed on assuming the liquid form.

If the volume of water were diminished in the same ratio at all temperatures, by the abstraction of caloric,

we might arrive at a proximate estimate of the absolute quantity of caloric which it contains. For example, it is known that water is diminished about one twenty-second of its volume on reducing its temperature 180°, viz., from 212° to 32°. If then it be assumed that the pores of water are 20 times greater than its solid atoms, (and Newton supposed that they were double this estimate,) it would require the abstraction of 3600°, to deprive it of all its caloric, provided the volume continued to diminish in the same ratio. But as it has been found that below the freezing point of mercury, its volume contracts in a greater ratio than at higher temperatures, it is probable that the same thing may be true of other bodies.

When we consider the vast abundance and importance of oxygen and hydrogen in the economy of nature, it becomes obvious, that a correct mode of ascertaining the relative quantities of caloric which they contain would throw new light on all the relations of ethereal and ponderable matter. All the waters of the earth are composed of oxygen and hydrogen, in the proportions of eight to one by weight. When converted into vapour by solar caloric, and diffused through the atmosphere, water is connected with all the phenomena of meteorology. As a mechanical agent, running water is perpetually wearing down mountains, hills and elevated plains, and transporting them to valleys, lakes and seas.

As a chemical agent, water is slowly but constantly dissolving rocks, salts and metals, which are again precipitated in the crystalline or solid state. It forms a large proportion of all animal and vegetable bodies;

also, of many salts and rocks. As a constituent of the atmosphere, oxygen is indispensable to all the phenomena of vitality. It enters largely into the composition of nearly all acids, alkalies, native ores or metallic bases; and constitutes about one-fourth of the earth's crust.

The importance of carbon is not less manifest; forming, as it does, the basis of all organic matter. In combination with hydrogen, it constitutes the principal portion of the food by which we are nourished, and of the fuel by which we are warmed and kept alive during winter. According to the analysis of Gay-Lussac, and of Dr. Prout, it forms about one-half of lignin, or perfectly dried woody fibre. It is the chief ingredient in those immense subterranean forests of ancient vegetation, termed fossil coal; and which, perhaps, exceed in quantity an hundred fold, all the trees and plants that now cover the surface of our planet.

After all attempts to ascertain the specific heat of bodies had proved discordant and fallacious, a series of experiments was undertaken by MM. Dulong and Petit, the object of which was to discover what relation existed between the atomic weights of various bodies and their capacities for caloric. The result of their researches was, that the specific heat of water was nearly three times that of sulphur and several of the metals, in which it was about one-half less than in some other elements; four times less than in others again, such as phosphorus and iodine; while in carbon it was nearly six times less than in water, or as 0·169 to 1·000. They also found that there was no uniform

relation between the quantities of caloric evolved during the combustion of different bodies, and the specific heat of their resulting products, the capacity of which was often the same before as after the process. Yet they maintained that *the atoms of all simple bodies have the same specific heat*, because when they vary, it is in multiple or submultiple ratios, or nearly so; and that the atomic equivalents of all bodies which do not accord with this assumed law, ought to be altered and made to agree with it. (*Ann. de Chim. et de Phys.* tome x.)

The recent efforts of Dr. Thomson to verify the hypothesis of Dulong and Petit, have not been successful, as will appear from the following table, representing the atomic weights of twenty-six simple substances, (compared with oxygen as unity,) their specific heat, and the resulting product. He observes, that "if the specific heat of bodies multiplied into their atomic weights be a constant quantity, it will follow that every simple atom is surrounded with the same quantity of heat." (*Records of Science*, April, 1836.)

	Atomic weight.	*Specific heat.*	*Product.*
Carbon	0·75	0·257	0·192
Silicon	1	0·187	0·187
Aluminum	1·25	0·150	0·187
Oxygen	1	0·236	0·236
Chlorine	4·5	0·827	0·372
Bromine	10	0·472	0·437
Hydrogen	0·125	3·293	0·412
Nitrogen	1·75	0·269	0·472
Sulphur	2	0·188	0·376
Arsenic	4·75	0·081	0·385
Antimony	8	0·047	9·376
Tellurium	4	0·091	0·364
Iron	3·5	0·110	0·385

	Atomic weight.	Specific heat.	Product.
Nickel	3·625	0·108	0·375
Zinc	4·125	0·927	0·383
Lead	18	0·029	0·377
Tin	7·25	0·057	0·370
Copper	4	0·095	0·376
Bismuth	9	0·040	0·360
Mercury	12·5	0·029	0·362
Gold	12·5	0·029	0·378
Platinum	12	0·310	0·372
Cobalt	3·25	0·160	0·487
Phosphorus	2	0·385	0·770
Silver	13·75	0·056	0·770
Iodine	15·75	0·89	0·401
Mean of the whole			0·375

Dr. Thomson maintains, that if the atoms of carbon, silicon and aluminum were doubled, and those of phosphorus and silver reduced one-half, their specific heat would be about the same as the mean of the whole; and that the other deviations from this average ought to be referred to inaccurate experiments. But if, for the sake of argument, we admit his assertion, it would follow that an equivalent of water contains 5·85 times more caloric than one of carbon, silicon, or aluminum; 4·76 times more than an atom of oxygen; above two and a half times more than one of hydrogen, nitrogen, iodine, or cobalt; about 40 per cent. more than one of phosphorus or silver; for the specific heat of water is 1·125 when multiplied by its atomic weight. And that capacity is no measure of the relative quantities of caloric in different bodies, would appear from the experiments of Haycraft, De la Rive and Marcet, who found that equal volumes of all gases are equally heated and cooled by equal additions and subtractions of caloric.

The following experiments of Dulong and Hess, performed with a view of ascertaining the relative quantities of caloric evolved during the combustion of several gaseous bodies and a few metals, will be found more instructive.

Substances employed.	*Atomic composition.*	*Grammes of water raised 1° centigrade.*
1 Litre of Hydrogen		3,102
1 " Light carburetted Hydrogen	CH_2	9,587
1 " Olefiant gas	C_2H_2	15,338
1 " Carbonic oxide	CO	3,130
1 " Cyanogen	NC_2	12,269
1 " Alcohol vapour	$C_4H_6O_2$	14,375
1 " Ether vapour	C_4H_5O	32,254
1 " Turpentine vapour	$C_{10}H_8$	70,607
Carbon vapour equal to 1 litre in the gaseous state		7,858

1 Litre of Oxygen gas with Iron	6,216
1 " " " Tin	6,508
1 " " " Antimony	5,352
1 " " " Zinc	7,577
1 " " " Cobalt	5,721
1 " " " Nickel	5,333
Mean of the six metals	6,151

To these may be added the results of M. Despretz, who found, that during the combustion of one pound of different substances, caloric enough was evolved to raise the following quantities of water from 32° to 212° F.

Substances employed.	*Quantities of water.*
1 lb. of Hydrogen	236·4 lbs.
1 " Charcoal from wood	75
1 " Olive oil	90
1 " Wax	95
1 " Ether	80
1 " Pure charcoal	78
1 " Alcohol	67·5

Substances employed.	*Quantities of water.*
1 lb. of Bituminous coal	60 lbs.
1 " Baked wood	36
1 " Wood with 20 per cent. water	27
1 " Turf, mean	27

From the table of Dulong and Hess we perceive, that during the combination of one atom of oxygen with two of hydrogen and one of carbon, as in light carburetted hydrogen, about three times more caloric is evolved, than by the combustion of the same volume of pure hydrogen; and that *one atom of carbon vapour, as it exists in carbonic oxide, gives out almost precisely the same amount of heat as an equal volume of hydrogen.* It would also appear from the same table, that during the chemical union of oxygen with the above metals, and its conversion into the state of solid oxides, about twice as much caloric is evolved as by the same bulk of hydrogen. So that if nearly the whole is afforded by the oxygen, it would be about eight times less than is given out by the same weight of hydrogen, corresponding with the difference between their atomic weights; for hydrogen is sixteen times lighter than oxygen: from which it would follow, that during the combination of oxygen with carbon and hydrogen, the atom of each gives out the same quantity of heat.

We further perceive, that during the combination of oxygen with two equivalents of carbon, and two of hydrogen, as in the combustion of olefiant gas, above four times as much caloric is evolved as by the union of one atom of oxygen with one of hydrogen; and that, although the coincidence is less exact between the quantities of heat evolved and the atomic consti-

tution of the remaining compound gases, it is sufficiently so to prove that hydrogen and carbon contain more caloric around their atoms than an equal weight of oxygen; and that equal volumes of the gases do not afford the same quantities of caloric. It must, however, be admitted, that the results of Despretz are at variance with those of Dulong and Hess, as he found that alcohol, ether, and other compounds of carbon and hydrogen, afforded much less caloric than in the gaseous state.

Let us next inquire whether the power of bodies to refract light may not afford a measure of the relative quantities of caloric around their particles. It was suggested by Newton, at the close of both the *Optics* and *Principia*, that the power of bodies to reflect, refract and inflect light, is in proportion to the quantity of ether that covers their surface and surrounds their particles; which ether he also regarded as the cause of cohesion, elasticity, solution, capillary attraction and gravitation. For example, he found that in spirit of wine, spirit of turpentine, olive oil, linseed oil, camphor and amber, which are highly inflammable bodies, the power of refracting light was two or three times greater, in respect to their densities, than in salts, rocks, or any other stony concretes, which are less combustible: and as it was higher in the diamond than in any other body which he tried, he arrived at the conclusion that it was a sulphureous or unctuous body coagulated, and would be found inflammable. (*Optics*, Book ii., pp. 240 and 250.)

That there is at least a nucleus of truth in this hypothesis of Newton, would appear from the nume-

rous experiments of Brewster, Wollaston, Biot, Arago and Dulong, who have found that in phosphorus and sulphur, as in all those bodies which are composed chiefly of hydrogen and carbon, with various proportions of oxygen and nitrogen, the power of refracting light is much greater in proportion to their specific gravities, than in any other bodies; and we have the most decisive proof that they contain proportionally more caloric around their particles, as might naturally have been inferred from all the phenomena of their combustion, volatility, and tendency to assume the gaseous state. But, so far as I am informed, no one has attempted to ascertain what relation exists between the latent caloric of bodies and their refractive powers, except my friend Mr. Dyar, whose views on the subject, if ever carried out, have not been published.

The most important experiments on the refractive power of gaseous substances with which I am acquainted, are those of M. Dulong, published in the *Annales de Chimie et de Physique*, xxxi. 154; as in the following table, which represents their refractive power and specific gravity, at the same temperature and pressure of the atmosphere,—to which I have added their atomic composition.

TABLE I.

	Refractive Power.		*Specific Gravity.*
Atmospheric air	1·000		1·000
Oxygen	·924		1·026
Hydrogen	·470		·685
Nitrogen	1·020		·976
Deutoxide of Nitrogen	1·030	NO_2	1·039
Protoxide of Nitrogen	1·710	NO	1·527

	Refractive Power.		*Specific Gravity.*
Carbonic Oxide	1·157	CO	·972
Carbonic Acid	1·526	CO_2	1·524
Marsh Gas	1·504	CH_2	.555
Olefiant Gas	2·302	C_2H_2	·980
Hydrocyanic Acid	1·531	NC_2H	·944
Hydrochloric Acid	1 527	HCl	1·245
Ammonia	1·309	NH_3	·591
Chlorine	2·623		2·470
Cyanogen	2·832	NC_2	1.818
Sulphuretted Hydrogen	2·187	HS	1·178
Sulphurous Acid	2·260	SO_2	2·247
Hydrochloric Ether	3·720	C_4H_5Cl	2·234
Phosgene Gas	3·936	CO,Cl	3·442
Sulphuret of Carbon	5·110	CS_2	2·644
Ether	5·197	C_4H_5O	2·580

From the above table we perceive, that there is no uniform relation between the refractive power of gases and what is called their specific heat, as admitted by M. Dulong; while it is equally obvious, that it is not in proportion to their specific gravity, nor to the size of their particles. It will be observed, however, that the refractive power of oxygen is nearly double that of hydrogen, which is sixteen times lighter: it therefore follows, that if their refractive powers be a measure of their latent caloric, hydrogen must contain about eight times more than an equal weight of oxygen; corresponding with the difference between their atomic weights and the relative quantities of caloric they evolve during the process of combustion. It is much to be regretted that we have no means of ascertaining the refractive power of carbon, separately, in the gaseous state. But as it is about three times higher in carburetted hydrogen, and four times greater in olefiant gas than in simple hydrogen, we are authorized to

conclude, that a pound of hydrogen contains six times more caloric than the same weight of carbon; or that the particles of each are associated with the same quantities of caloric.

And as the refractive power of nitrogen is 2·17 times that of hydrogen, the specific gravity of which is fourteen times less than that of nitrogen, it follows that hydrogen must contain 6·45 times more caloric around its particles than the same weight of nitrogen. Nor can there be a rational doubt, that if the experiments were rigidly accurate, the refractive power of hydrogen would be just eight times that of oxygen, and seven times that of nitrogen; consequently, that the true atomic weight of nitrogen is seven compared with hydrogen, as maintained by Dalton and Berzelius, instead of 14, as supposed by the majority of chemists. And if such be the fact, it follows, that hydrogen, carbon, nitrogen and oxygen, (which are by far the most important of all the elements, because the most active, and because they are the principal constituents of organized bodies,) contain the same amount of caloric around their chemical atoms.*

* There is, therefore, reason to believe, that when the refractive power of all bodies shall be rightly ascertained, we shall have a more certain method of determining their atomic equivalents, many of which are acknowledged to be doubtful; and that we shall be able to correct errors in regard to the chemical composition of bodies, that have arisen from imperfect analyses. It must, however, be admitted, that in the present state of science, the refractive power of compound gases, liquids and solids, does not always correspond with that of their constituents in the separate state; a circumstance which may be owing in part to imperfect experiments, and partly to the fact, that during nearly all chemical combinations

A still more direct and cogent proof that the refractive power of bodies is in proportion to the amount of caloric around their particles is, that it is higher in water than in ice, higher in fluid than in solid sulphur, as it is in all those bodies which are composed chiefly of carbon and hydrogen, such as alcohol, ether, the volatile and fixed oils, than in water, the specific gravity of which is greater, as will be seen from the following table, taken chiefly from the experiments of Sir David Brewster. It will also be seen, that it is higher in the diamond, which consists of pure carbon, (condensed by an immense pressure,) than in any other solid body, if we except phosphorus and sulphur, both of which are highly inflammable, and afford very large quantities of caloric by combustion.

TABLE II.

REPRESENTING THE REFRACTIVE POWER AND SPECIFIC GRAVITY OF DIFFERENT CLASSES OF BODIES IN THE LIQUID AND SOLID STATES.

	Refractive Power.	*Specific Gravity.*
Water	1·335	1·000
Ice	1·307	·950
Alcohol	1·372	·794
Ether	1·358	·700

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and decompositions, caloric is either absorbed or given out, as will be shown hereafter. But as we have found that in hydrogen, carbon and oxygen, it coincides so nearly with the quantities of caloric they give out during combustion; and is nearly the same in several compound gases, when reduced from the refractive power of their elements, the subject is one that merits the most careful investigation. For if there be no uniform ratio between the refractive power of bodies and their specific gravities, while in the best-ascertained cases it accords with the quantities of caloric they afford by combustion, it is difficult to resist the conclusion that caloric is the cause of refraction, as it is of attraction and repulsion.

	Refractive Power.	*Specific Gravity.*
Melted Beeswax	1·450	·960
" Spermaceti	1·470	·940
Oil of Lavender	1·457	·877
" Caraway	1·491	·940
" Turpentine	1·475	·890
" Camphor	1·487	·988
" Lemon	1·481	·847
" Olives	1·470	·910
Castor Oil	1·490	·969
Melted Sugar	1·555	1·500
Gum	1·554	1·400
Acetic Acid	1·396	1·062
Malic Acid	1·395	1·090
Nitrous Acid	1·396	1·450
Nitric Acid	1·406	1·480
Sulphuric Acid	1·440	1·840
Phosphoric Acid	1·544	2·687
Rock Salt	1·557	2·600
Quartz	1·548	2·600
Garnet	1·515	4·000
Calc Spar	1·665	2·700
Arragonite	1.693	2·800
Sapphire, blue	1·794	4·200
Arsenic	1·811	5·900
Calomel	1·970	7·200
Carbonate of Lead	2·084	6·400
Sulphur, native	2·038	2·033
" melted	2·148	1·990
Phosphorus	2·224	1·770
Diamond	2·470	3·591
Chromate of Lead	2·926	6·000
Mercury	5·000*	13·500

* The refractive power of mercury was determined by M. Arago from its power of reflecting light. But it was supposed by Newton that both refraction and reflection are owing to the same cause, and that the one is a measure of the other. Should this hypothesis be well founded, we have an easy method of ascertaining the refractive power of solid and opaque bodies. That M. Arago has very closely approximated the truth in regard to mercury, would appear from the high refractive power of calomel, as determined by Brewster. And that it is nearly the same in lead as in mercury, would appear

It has been recently discovered by the researches of chemists, that many bodies composed of different elements, the atoms or particles of which vary in size, exhibit the same crystalline form, as in the phenomena of *isomorphism*, from ἰσος, equal, and μορφή, shape.* It has been also ascertained that other bodies composed of the same elements of ponderable matter in the same

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from the high refractive power of its compounds, as in the carbonate and chromate of lead; while it is well known that gold, platinum, silver, iron, tin, zinc and other dense metals, reflect a much larger proportion of light (when smoothly polished) than the same surface of rocks, gems, glass, or the lighter metals; and the latter more than water, alcohol, ether or the oils. It would, therefore, appear that the denser metals contain from two to four times more caloric around their particles than an equal bulk of water, but very much less than an equal *weight* of water, sulphur, phosphorus, or any of the compounds of oxygen, carbon, hydrogen and nitrogen.

* In regard to the rationale of isomorphism, Mitscherlich laid it down as a law, that "the same number of atoms combined in the same way, produce the same crystalline form, which is determined by the number and position of the atoms, independent of their chemical nature." According to this view, the arseniate and phosphate of soda, the protoxides of iron, zinc, copper, nickel, manganese and some other salts, are of the same form, because composed of the same number of particles arranged in the same manner. But the atomic weight of arsenic acid is one hundred and fifteen, and of phosphoric acid, seventy-two. The seleniate of soda is also identical in form with the sulphate of soda, although the atomic weight of selenic acid is sixty-four, and that of sulphuric acid, forty. It is therefore not easy to comprehend why they produce the same form on uniting with soda, without supposing that sulphuric acid contains a larger amount of caloric around its particles, the volume of which would be thus increased, so as to approximate the magnitude of those of the selenic acid.

proportions, assume totally different crystalline forms, as in the phenomena of *dimorphism*.

For example, it was found by Scoresby, that in the arctic regions water congeals in an almost endless variety of geometrical figures, of which he enumerates five classes; the *lamellar*, the *stelliform*, (which is the most general, and occurs chiefly when the temperature is near 32°;) the *regular hexagon*, which becomes thin and diminishes in size as the cold increases; *aggregations of hexagons*, which occur chiefly at low temperatures; and lastly, *combinations of hexagons with spines or radii*. (*Arctic Regions*, vol. i. p. 432.) It is also related by Dr. Daniel Clark, that on one occasion at St. Petersburg, when the temperature of the air was five degrees below the freezing point, every particle of snow which he examined consisted of a wheel or star, with six equal rays, bounded by circumferences of equal diameters. They all had the same number of rays branching from the centre; and were about the size of a pea divided into two equal parts. (*Travels in Russia.*) When this subject is better understood, it will be found that those crystals of snow which are found at the same time, in still weather, and at the same temperature, have generally the same form; but when produced at different times, and at different temperatures, they exhibit different forms; of which Kœnitz thinks there are several hundred; and many of which he has observed that were not figured by Scoresby. (*Meteorology*, p. 131.) It is therefore clear, that the form of crystals depends on the arrangement of their particles, and not on their essential nature. *But if it be a fact that caloric is the agent which regulates the distance*

of atoms or particles from one another, and causes all their movements, whether of union or separation, it must obviously determine the various modes of their arrangement, whether in the solid, liquid or gaseous states. And as the atomic composition of water in every state is the same, it is impossible to comprehend why it should assume various crystalline forms, as observed by Kepler, Cassini and Scoresby, without admitting that its particles are surrounded with different quantities of caloric, on assuming these different forms.*

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* The various crystalline forms are now generally arranged in six divisions or systems, as in the following classification by Gustav Rose: 1. The *cubic* or *tessular*. 2. The *square prismatic*, (in which the lateral edges, like the terminal planes, are parallel.) 3 The *rhombohedric*. 4. The *right prismatic*. 5. The *oblique prismatic*. 6. The *doubly oblique prismatic*.

In all crystalline bodies the form is angular, and the arrangement of their particles rectilinear. In those of which all the sides and angles are alike, the expansion by caloric is equal in all directions, as in the cube, the regular octohedron, and the rhomboidal dodecahedron; and the refraction of light is single, when they are of uniform temperature and density, as it is in the transparent gases, vapours, liquids and glass. But in the square prismatic and rhombohedric classes, the expansion by caloric is dissimilar in two directions; while in the right prismatic, the oblique prismatic, and the doubly oblique prismatic, it is dissimilar in three directions. And when a ray of light is made to pass through any of these bodies, or through glass unequally cooled, and solids of unequal density, whether from unequal temperature or pressure, it is refracted in two different pencils, more or less inclined to one another, according to the molecular arrangement of the body, and the direction in which the pencil is incident; thus producing all the phenomena of double refraction, which also occurs when it passes through resins, gums, jellies, horn, shells, bones, elastic integuments and animal lenses. Whenever a ray of light is thus divided, one of the trans-

It has been also discovered by Rose, that at the temperature of 50°, carbonate of lime assumes the form of rhombohedric crystals, as in calc spar; whereas, at the temperature of 150°, it takes the cubic form, as in arragonite, the composition of which is the same. And when rhombic crystals of calc spar are heated to 212°, they are changed to the cubic form, without any change in its chemical composition,—if we except the addition of caloric, which is the cause of all molecular aggregations, and therefore the creator of forms. Corresponding with the foregoing facts, Mitscherlich has shown that the mutual inclination of the crystalline planes in calc spar is altered eight and a half minutes of a degree between the temperature of 32° and 212°; while in other cases it varies nearly 1° in different specimens of the same salt. For a full account of his discoveries, see *Ann. de Chim. et de Phys.*, tome xiv. 172; xix. 350; xxiv. 264, 355.

In accordance with the above facts, it has been discovered that on crystallizing from solution in the bisulphuret of carbon, or oil of turpentine, at temperatures below 100°, sulphur assumes the octohedric

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mitted rays is said to be polarized; that is, its properties are so far changed that it is incapable of undergoing reflection or refraction, except at certain angles; or of transmission through transparent bodies, except in particular positions. For example, a plate of tourmaline permits the ray to be transmitted in one position, but in a position perpendicular to that it arrests and stifles it, because in these two rectangular directions its particles are differently arranged. It is therefore manifest that all the phenomena of crystallization, the reflection, refraction, double refraction, polarization, and doubtless the diffraction of light, are immediately connected with the theory of caloric.

form, with rhombic bases; but that when melted by itself and allowed to cool slowly, it takes the form of an oblique rhombic prism on solidifying at 230°. (*Graham's Elements of Chemistry*, p. 189.) It has also been ascertained that pure carbon occurs in the form of regular octohedrons, as in the diamond, but in six-sided plates in graphite. And Professor Johnston has recently shown that there is a large class of bodies composed of the same elements in the same proportions, which crystallize in two, if not more primitive forms. But since the time of Dr. Black, chemists have attended so little to the agency of caloric in the various transformations of matter, that they have scarcely ranked it among their elements, although it constitutes by far the largest proportion by volume of solid bodies.

Among the most civilized nations of antiquity, it was supposed that everything in nature is composed of four primitive elements, which they termed *earth*, *water*, *air* and *fire;* to which Aristotle added a fifth. But the tendency of modern science has been to increase the number, until it has extended to sixty-two, all of which are regarded as simple, because chemists have not yet been able to resolve them into fewer elements. There is reason, however, to believe that none of our chemical atoms and elements are perfectly simple, if we except caloric, which also exists in a great variety of states, as will be shown hereafter; and that it is only in the subtilized form of light that we can hope to discover the ultimate constitution of ponderable matter.*

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* For example, if it be true that all the reputed elements are

In accordance with the hypothesis advanced by Newton in one of his *Optical Queries*, that light and

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convertible into light, and that light is decomposable into seven primitive rays by prismatic refraction, as maintained by Newton, or into only three fundamental colours, when analyzed by absorbent transparent media, as maintained by Brewster, it will follow that what we call simple bodies are composed of one, two, three or more of the primitive elements which constitute white light. Now it is worthy of remark, that hydrogen is the most elastic of all gaseous bodies, and affords during combustion an almost perfectly blue light; while, according to the experiments of Newton, the blue rays are more refrangible than any others except the violet, which is not a simple colour according to Brewster, but composed chiefly of *blue*, with small proportions of *yellow* and *red;* which he regards as the three primitive rays, and the elements of all compound colours. It is therefore probable that the blue and violet rays are more refrangible than the others, for the same reason that hydrogen, of which they are formed, is the most elastic of all known bodies, viz. because it contains more caloric around its particles in proportion to their size. And it was supposed by Newton that the atoms of light diminish in size from the red to the violet extremity of the spectrum. Again, as sulphur burns with a blue, and iodine with a violet light, (which contains small proportions of the other rays,) they may be composed chiefly of hydrogen, with some other base or bases; and cannot be otherwise decomposed than by expanding them into the subtile form of light. On the other hand, during the combustion and ignition of potassium, strontium, lithium, sodium and magnesium, they afford chiefly red light, with small proportions of the other coloured rays; therefore must all be composed principally of one element, the primitive atoms of which are red, while those of hydrogen (which is the basis of sulphur, iodine, and perhaps some other bodies,) are blue. Chloride of sodium also affords an orange-coloured light; while in that of chlorine, silver, copper and some other bodies, there is a predominance of greenish rays; so that if green light be composed chiefly of yellow and blue, as maintained by Brewster, all bodies that burn with a green light must be compounds of two or more

common matter are mutually convertible into each other, it has been recently maintained by Sir David Brewster, that "*the particles of light are identical with the ultimate atoms of bodies, and that there is a specific affinity between definite atoms and definite rays*, though we do not understand its nature."* (*Transactions of the Brit. Association*, vol. i. p. 231.) He also observes in another work, that "when a portion of light enters a body, and is never again seen, we are entitled to say that it is detained by some power exerted over it by the particles of the body; that it enters into chemical combination with them, and produces the various chemical effects by which their colours are changed, and the juices of plants elaborated,"—to which he adds, "It is not easy to allow that such effects are produced by undulations of an ethereal medium. (*Optics*, chap. xxxiv.)

That every description of ponderable matter is actually convertible into light by a sufficiently intense heat, or by electricity, will appear from the following undeniable facts:—

1. That the quantity of light generated by ordinary combustion, friction or percussion, is always in pro-

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primitive elements; while others, again, which afford different proportions of all the coloured rays of the spectrum, are still more complex.

* A similar doctrine seems to have prevailed among the ancients, for the sceptre of the Egyptian *Pthah* was painted with four colours, which were attributed to the four elements. Plutarch also says, that Pythagoras maintained the existence of four primitive colours, and that Zeno regarded *colours as the first configuration of matter;* while, according to Plato, they are produced by the reflection of light from bodies to our eyes. (*De Placit. Philosophorum.*)

portion to the rapidity with which ponderable matter is ignited and volatilized.

2. That the colour of light thus produced always depends on the species of matter employed.

3. That the electric spark, like that produced by the collision of flint and steel, consists of exceedingly minute portions of ponderable matter in a state of incandescence, as will be shown hereafter by the decisive and beautiful experiments of Fusinieri.

4. That when the electric fluid is transmitted through the vacuum of an air-pump, little or no light is produced, as proved by the experiments of De Luc, and afterwards by those of Sir H. Davy.

5. That the most intense heat of a voltaic battery never produces any light, except when acting on ponderable matter; consequently, that light and heat are not identical,* as maintained by some modern theo-

* That caloric is a constituent of light, (as it is of all other bodies,) and is the active principle in its generation, is evident from the fact, that the most refractory gems and metals are transformed into luminous incandescent particles by a sufficiently intense heat, definite measures of which are required to produce the effect on different species of matter. It has also been proved by the experiments of Hulme, Dessaignes, Macartney and others, that every species of phosphorescence is promoted (for a time) by moderate heat, and always extinguished by the coldness of freezing mixtures; while others have found that the light of luminiferous insects is much greater in vessels of oxygen gas than in common air. But that caloric is a distinct essence, and may exist independent of light, is manifest from the fact, that it converts solids into liquids, vapours and gases, in the midst of perfect darkness; while it radiates from the earth during night, as it does from boiling liquids and other hot bodies, without being attended with any light.

rists; and that neither of them is generated by the mere vibrations of an ethereal medium.

In accordance with the foregoing facts, it has been found that each of the primitive rays produces specific changes of colour in different bodies; that the blue and violet rays of the spectrum change the white chloride of silver to a dark-violet hue; whereas the red rays change it to a rose colour; and that the same change of colour is produced on the protochloride of lead and the oxide of mercury, when moistened and exposed to the red rays of the spectrum, as in the experiments of Scheele, Sennebier, Davy and Seebeck: —that a piece of white paper stained yellow with a solution of guiacum in alcohol, was turned green in five minutes by exposure to sunshine, but remained unaltered for several months in the dark; and that when the yellow paper was made green by exposure to the violet rays, its original colour was restored by exposure to the red rays of the spectrum, as shown by the experiments of Wollaston.

The chemical agency of light is still more strikingly illustrated in the production of those accurate pictorial delineations of objects termed Daguerreotypes, which are formed by the immediate influence of the regal sun. Moreover, that there is "a specific affinity between definite atoms and definite rays," is evident from the fact, that bodies repel and reflect certain rays, while they attract and absorb others. For example, it was found by Sir David Brewster, that red transparent solutions and glasses permitted the red rays of the spectrum to pass freely through them, but

absorbed and obliterated the other rays;* that blue media permitted rays of the same colour to pass through them, but absorbed the other rays; and that green media absorbed the rays at both extremities of the spectrum, but the red most where it verges to blue, and the violet most where it verges to yellow. Nor is it more remarkable, that bodies should absorb one or more primitive rays, and reflect or transmit others, than that certain elements of ponderable matter should have an elective affinity for some, and an antipathy for other elements; the rationale of which is doubtless the same in both cases, and must be sought in the fact, that as the different rays of light are of different temperatures, so are the elements of ponderable matter associated with different quantities of caloric. And it will be found hereafter, that no chemical union of bodies ever takes place without the

* If in our cathedrals, colleges and other public buildings, were judiciously placed a few windows composed of perfectly red, yellow and blue glasses, (to which might be added combinations of these colours,) the mind would be elevated, refined and instructed, on beholding such a vivid display of all that is most beautiful in light, when thus decomposed, and reduced to its primitive elements. The effect would also be much improved by arranging the colours so as to produce an imitation of the rainbow; to which might be added other appropriate symbols, and even inscriptions, written in letters of light. Never shall the author forget the emotions of delight and admiration he experienced on first looking at the sky through a fine ruby glass,—when it presented the appearance of a vast dome of lurid flame; and the whole face of the earth, as if by enchantment, was suddenly dyed of a gorgeous crimson hue. We little think how cheaply some of the highest pleasures of existence may be purchased.

transition of caloric from one to the other, attended, in most cases, with a change of temperature.

But if the ultimate atoms of ponderable matter be identical with those of light, and the latter consist of seven primitive rays, as supposed by Newton, it follows that the sixty-two elements enumerated by chemists are not simple bodies, but compounds of two or more primitive elements, as before suggested; or, that if light consist of only three primitive rays, united with caloric, everything in nature must be composed of four elements. Nor is it possible to admit with Newton, that the blue and indigo are distinct primitive rays; while it is certain that all the known varieties of colour may be produced by combinations of *red*, *yellow* and *blue;* which, as Brewster has shown, overlap each other, and reach quite across the spectrum.

What then becomes of the enormous quantities of light perpetually radiated throughout the solar system? This is doubtless one of the most curious, important and comprehensive problems in the whole range of physics, and deserves the profoundest attention of philosophers. One thing is certain, that if light be matter, it cannot be annihilated, any more than the great fountains from which it emanates; that whatever falls upon the earth, and is not reflected or radiated from it into surrounding space, must combine with, and become a constituent portion of its surface; that certain rays produce specific chemical and vital effects; while the various powers of different bodies to decompose white light by absorption, transmission, reflection, refraction and polarization, cause an endless diversity of colours. Light, then, is not

only a revelation of all that is grand and beautiful in the outward universe, but the agent by which all its operations are carried on. It is therefore probable, that when fully understood, it will enable us to explain whatever is now mysterious in the ultimate mechanism and laws of nature.

And if "the particles of light be identical with the ultimate atoms of ponderable matter," the question naturally arises, whether all the planets and satellites of our system may not be so many masses of embodied light, which is first aggregated into nebulæ, and then into comets, that go on gradually augmenting in size, by constant additions of light, until, after enormous periods of time, (compared with which our geological epochs are mere fractions,) they arrive at maturity, or until, by the expenditure of his substance, the sun is so far reduced in magnitude, that the centrifugal power of his rays becomes inferior to the centripetal pressure of the surrounding ether—when they would gradually approach, and finally in succession fall into the sun? In short, whether the ponderable matter of the sun and fixed stars is not perpetually expanded by caloric into the subtile form of light, which is as constantly reconverted into the matter of planets and satellites.

This theory enables us to answer the important question, "What becomes of light?" while it affords a more intelligible explanation of the manner in which cosmical bodies are generated and finally destroyed, than any merely metaphysical hypothesis—unless by metaphysics we understand the universal Science of

Ontology, or of whatever exists.* It also enables us to comprehend why the distances of the planets from

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* The periodical creation, destruction and reorganization of worlds, was a fundamental doctrine of the ancient Hindu cosmogonists, who maintained that they are all emanations from the eternal *Brahm*, and that after enormous periods of time they return to the primitive source of their existence. But the mighty *Brahm* was a personation of the entire universe, in its two-fold character of spirit and matter, or nature active and passive. In the *Vidás*, the eternal *Brahm* is represented as perpetually sacrificing a portion of his immensity in the formation of worlds, which he creates and recreates for the purpose of multiplying happiness. According to this ancient theory, the universal *Brahm* comprehends the innumerable fixed stars or suns that throng the infinitude of space, and from which proceed myriads of planetary systems in endless succession. In the *Rich Vidá*, the solar orb is invoked as "the godhead from whom all proceed, and to whom all must return;" as we are informed by Sir William Jones. In regard to what is said in the *Puranas*, concerning the sleep of *Brahmá*, during which the universe, after having existed for countless ages, fades away into an invisible state, and again emerges into being when he awakes—it must be viewed as the dream of oriental transcendentalism, or as an allegorical account of those cosmical revolutions described by Sallust, who tells us that in the course of certain vast periods, the whole universe undergoes mutations which are equivalent to the entire destruction of worlds, and the formation of others from their ruins. (*De Diis et Mund.*, c. vii., xvii.) The same doctrine (which is in actual accordance with all known analogies in nature) may be found in the third book of *Seneca's Natural Questions*.

We are further informed by Diogenes Lanteus, that according to Heraclitus, all things were originally formed from fire, which, in its ordinary state of flame, is light. And we read in the first chapter of Genesis, that light was created before the earth, or the sun, moon and stars. The fact is, that in all the ancient cosmogonies, light is represented as the first of created things. Among the Egyptian sages, it was the first-begotten of *Osiris* and *Isis*, who were personations of spirit and matter, or of the active prin-

each other augment in nearly definite ratios, from Mercury to Uranus; why they increase in magnitude (if we except Mars and the asteroids) from Mercury to Jupiter; and why their equatorial exceeds their polar diameters. For example, it is probable that if light obey the same laws as other projectile bodies, a much larger proportion of what is radiated from the sun would lose its original force and velocity at the distance of Jupiter, Saturn and Uranus, than at that of any one of the planets nearer to the sun; so that a corresponding amount of luminous matter would be aggregated into comets, which may successively fall into those great masses and their satellites,—in the same way that many thousand meteoric stones, and

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ciple in nature, and the passive matter out of which everything was formed. In the *Orphic Hymns*, light is called πρωτογονος, or first-begotten of the ether and chaos, which the ancients universally regarded as the origin of all things. Nor is it more difficult to comprehend the generation of worlds from the matter of light, than their creation out of nothing—a doctrine which involves the incredible supposition, that during the whole eternity that preceded the act of creation, the Deity existed alone in the vast solitude of his own immensity unemployed. It is far more in accordance with the attributes of infinite wisdom and goodness that belong to the author of the universe, to suppose that he has been always employed in the creation of worlds, and the diffusion of happiness, than that he should have commenced at some finite period, or, as the Brahmans tell us, that he should suffer them all to fade away, fall into a periodical state of practical nonentity. As to Laplace's theory, that the planets of our system were formed by a gradual contraction of the sun's atmosphere, there is no assignable reason why the sun should have thrown off such an atmosphere at one time rather than at another. Nor would such an atmosphere, if aggregated, form the smallest satellite of our system.

showers of stones, have fallen from unknown heights upon our planet, since the historical era,—*a fact which clearly demonstrates that the earth has been augmenting in size, independently of the constant additions of matter it receives from the sun in the form of light.* And as it is equally evident that the tropical portion of planets receives much greater quantities of light from the sun than the middle and polar latitudes, this fact affords a more satisfactory reason for their equatorial protuberances than the prevalent theory, which refers them to the rapid diurnal motion of their equatorial zones.

If the foregoing views be well founded, it follows that light, in connection with caloric, which is the active principle in its generation, and always forms a constituent portion of it, is the primitive basis of all material existence,—or the physical *Ens entium;* consequently cannot be resolved into the mere vibrations of an ethereal medium, as maintained by many distinguished mathematicians of the present age.

That the vibratory theory of light is not a true representation of nature, would further appear from the following considerations:—

1. That it does not explain what the ether is, nor what causes it to vibrate.

2. That light is propagated in straight lines, and will not pass through a bent tube; whereas vibrations move around interposing bodies, which obstruct the passage of light, as maintained by Newton.

3. That the wave theory does not explain the generation of light by combustion, ignition, friction and percussion; how it is connected with caloric and elec-

tricity; *nor why ponderable matter* is essential to its production.

4. That it does not explain the decomposition of light by prismatic refraction, absorption and transmission; nor how it modifies the chemical and vital properties of ponderable matter; while "it leaves the whole subject of colours, both in opaque and transparent bodies, involved in profound obscurity." (WHEWELL.)

5. That in adopting the theory of undulations, "we are called on for acts of faith, and certain admissions must be made at every step," as acknowledged by Sir John Herschel, who is certainly one of its ablest advocates.

6. That as the different colours of light depend on the species of ponderable matter employed in its generation, they cannot be resolved into different numbers of ethereal vibrations.

7. That when a sunbeam impinges on objects, it produces mechanical, chemical and vital changes; causes pain and inflammation of the eyes; alters the colour, taste, odour and other sensible properties of bodies; effects which cannot be reconciled with the hypothesis that light is not a material substance.

The radical defects of the wave theory have been disguised by an imposing array of algebraical formulæ; while the most important facts connected with its history have been overlooked, or intentionally neglected; and that it is exceeding difficult to understand, is admitted by Mr. Whewell. In short, the amount of mathematical reasoning brought to its support, would seem to be inversely as the number of facts on which

it is based: for the very existence of the ether is assumed; while its vibrations are made longitudinal or transverse, just as the phenomena may require. And it might as well be said that the first mover in the steam engine is motion, as that light consists merely in the vibratory motions of an ether.

CHAPTER III.

ON THE LAW BY WHICH CALORIC PRODUCES THE OPPOSITE FORCES OF ATTRACTION AND REPULSION, CONTRACTION AND EXPANSION.

"That alone is true philosophy which repeats the words of the universe with fidelity, and is written, as it were, by dictation of the universe."—BACON.

THE doctrine that everything in nature is composed of two descriptions of matter, the one essentially active and ethereal, the other passive and motionless, was recognized by the most acute and profound sages of antiquity in every quarter of the civilized world. But notwithstanding they all regarded elementary caloric as the prime mover, they seem to have overlooked the law by which it repels its own particles, and tends to combine with those of ponderable matter, with forces that vary inversely as the squares of the distance, so as to produce all the centrifugal and centripetal forces of nature. The same observation applies equally to Bacon, Descartes, Newton and other modern philosophers, who, although they sometimes referred all the operations of nature to what they called a *spirit* or *pneumatical body*, a *materia subtilis*, a *subtile ether*, &c., they never identified it with any known principle, nor explained how it causes both attraction and repulsion, union and separation.

Why then does caloric repel its own particles, and attract those of ponderable matter, with forces that vary inversely as the squares of the distance? To this primary and leading question I answer, that caloric repels its own particles because they are of the same nature, and attracts those of ponderable matter because they are of a totally different nature; that in every variety of state caloric is an essentially active principle, and incomparably more refined than any description of ponderable matter, even when expanded into the subtile form of light; for it permeates the most dense and opaque bodies, which are wholly impervious to light. And that the forces of caloric diminish in proportion as the squares of the distance augment, is obvious from the fact, that all ethereal emanations are necessarily diffused in the same ratio, on radiating from any given centre.*

That atoms of the same nature repel one another, and attract those of a different nature, would appear from the best-known phenomena of chemistry and physical optics. For example, it has been long known that similarity of properties among the elements of ponderable matter causes them to repel each other, as if by a mutual antipathy; but that diversity of properties is favourable to chemical combination. We

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* It would therefore seem to follow, that there must be a limit to the diffusion of caloric; that it is not infinitely subtile and divisible; but that there must be a definite number of particles in any given quantity of it. It is only by its extension throughout illimitable space that it can be regarded as infinite; for we shall find that, while it governs all the operations of the material universe, it is itself governed by invariable and necessarily fixed laws.

have also found that transparent media transmit rays of light of their own colour, but attract and absorb those of different colours.

That caloric is a self-active principle has been already shown by its power of moving itself, and of giving motion to other bodies, the activity of which is augmented by every addition, and diminished by every abstraction of heat; proving, that if the particles of ponderable matter could be wholly deprived of caloric, they would be passive and motionless. At the same time it is highly probable, that if universal space were filled with caloric alone, (without any ponderable matter,) it would also be inactive, and constitute a boundless ocean of powerless or quiescent ether, because it would then have nothing on which to act. And we shall find that, however inactive of itself, ponderable matter has certain properties by which it modifies and controls the actions of caloric, both of which are governed by immutable laws that have their origin in the mutual relations and specific properties of each.

I now proceed to show, that *all the expansions and contractions of gaseous bodies depend on the relative proportions of caloric and ponderable matter of which they are composed.* For example, the atoms of hydrogen are smaller, and contain a larger amount of caloric around them, in proportion to their size, than those of any other gas; the consequence of which is, that its elastic force is such, that no mechanical pressure hitherto employed has been sufficient to condense it into the liquid form.* And it was found by Perkins, that

* Under the pressure of the atmosphere, and at the temperature of 60°, hydrogen is 15,480 times lighter than water, the pores of

atmospheric air (which is composed of oxygen and nitrogen in a state of mechanical mixture) may be submitted to a pressure equal to 1200 atmospheres, without being perfectly condensed into the liquid form. (*Philosophical Transactions*, 1826.)

But when three volumes of hydrogen unite chemically with one of nitrogen, they contract into two volumes of ammonia, the elastic force of which is so far diminished that it may be condensed into the liquid

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which are 40 times larger than its solid particles, according to Newton. It is therefore evident, that the pores of hydrogen exceed the diameters of its particles several thousand times, and, perhaps, to the same extent, that the spaces between the different planets exceed their mean diameters. What, then, is the cause of the stupendous force by which the particles of hydrogen are kept at such comparatively great distances from one another? Is it some virtue, property, or condition termed polarity? Or is it owing to the existence of certain hypothetical immaterial spheres of repulsion around its particles? Is it possible that masses, and the atoms of which they are composed, are capable of acting upon each other at comparatively great distances without an intervening medium? That the volume of gaseous bodies is augmented by every addition of caloric, has been proved by the experiments of Gay-Lussac, who found that 1000 cubic inches of common air were expanded to 1375 cubic inches by raising its temperature from 32° to 212°. It was further ascertained by Dulong and Petit, that the same law of expansion is true of atmospheric air and hydrogen, up to the temperature of 680°; from which they concluded, that it was true of all gases, and at all temperatures. (*Ann. de Chim. et Phys.*, vii. 120.) Dr. Dalton also found that the elastic force of steam was equal to the weight of the atmosphere at 212°, but was equal to the pressure of six atmospheres when raised to 320°. And we learn from the experiments of Perkins, that when water is confined in very strong vessels, it expands with a force equal to the pressure of 20 atmospheres when raised to the temperature of 419°.

state by a pressure equal to 6·5 atmospheres, or by cold alone at the temperature of 46° below 0° F. And when two volumes of nitrogen combine with one of oxygen, the elastic force of the resulting compound gas is so far diminished, that it may be liquefied by a pressure equal to 44 atmospheres at the temperature of 32°, as first shown by the experiments of Sir H. Davy; or by a pressure equal to 50 atmospheres at the temperature of 45°, according to Faraday. What then is the rationale of these curious phenomena? Is the sphere of repulsion in the elementary gases exchanged for one of attraction as they unite chemically, with contraction of volume and diminution of elasticity? Or how many immaterial and imaginary spheres of attraction and repulsion are required to explain the phenomena of solidity, liquidity and vapourization? The summary answer to these queries is, that "*the self-repulsive power of caloric is counteracted and diminished by its affinity for ponderable matter, by which the ethereal atmospheres are drawn into a smaller compass.* The reduction of volume and elastic force are referable wholly to this one cause.

Perhaps the principle cannot be better illustrated than by a consideration of the statical and dynamical changes that are produced on hydrogen and chlorine, by their mutual action upon each other.

We have seen, that the specific gravity and atomic weight of chlorine are 36, compared with hydrogen as one; and that the elastic force of hydrogen is immense. It has been also shown by Faraday, that the elastic force of chlorine is so low that it may be liquefied by

a pressure equal to four atmospheres at the temperature of 60° F.

But when one volume of chlorine is made to unite with one of hydrogen, they form two volumes of hydrochloric acid gas, the specific gravity of which is 18·5; or a mean between that of its constituents. During this combination, the hydrogen loses the greater part of its elastic force, while that of the chlorine is greatly augmented. That is, *a definite proportion of caloric passes from the smaller atoms of hydrogen to the larger atoms of chlorine, by which the latter are removed farther from one another.* Nay more, *it is by virtue of this transfer of caloric that the atoms of hydrogen are forced into chemical union with those of chlorine, and their separate individuality destroyed.* In other words, all the above changes, including that by which the gases are united and identified, are referable wholly to the transition of caloric from the one to the other.

It will be shown hereafter, that no chemical combination of any one body with another ever takes place, without a simultaneous passage of caloric or electricity from one to the other; that if water and other liquids could exist as such without caloric, (which is impossible,) they could not combine with salts, metals and rocks; and that the diminution of bulk which attends the combination of liquids with solids, is owing to the same law which determines the reduction of volume and elastic force of gases and vapours. The most simple illustration of combination effected by the attraction of caloric for ponderable matter, is that by which steam is condensed by water or ice, and intimately combined with their particles. When a certain

proportion of steam is mixed with cold water, its volume and elastic force are destroyed by the same attraction of caloric for ponderable matter which causes liquids to combine with, and dissolve solids, or which causes gases to combine chemically, with contraction of volume and diminution of elastic force.

There is no limit to the application of this doctrine in the phenomena of chemistry.

If a piece of ice be introduced into a vessel full of ammoniacal gas, the latter disappears rapidly, and the ice is melted, forming a chemical solution of ammonia. Now it is obvious, on a moment's reflection, that the volume and elasticity of the ammoniacal gas are destroyed by the transfer of caloric from one to the other. It is equally true, that the ammonia is chemically combined with the ice by the same attraction, as will be proved when I come to treat of chemical solutions. Again, if one volume of hydrochloric acid be mixed with one volume of ammoniacal gas, they may be made to combine rapidly with evolution of much heat, when they lose the gaseous or elastic state, making a solid crystalline salt, (sal ammoniac,) of a cubical or octohedral form. The atomic weight of the acid is 37, and that of the alkali 17. (See *Table of Atomic Weights*, p. 67.)

In this case, there is an attraction of caloric for the larger particles of the acid, by which those of the ammonia are forced into chemical combination with them, forming compound particles of still larger size, the weight of which is 54, compared with hydrogen as unity.

Thus it is evident that *the repulsive power of caloric,*

on which the volume and elastic force of gases depend, is counteracted and diminished by its *affinity for ponderable matter, and that this attraction augments in a certain ratio as the size of the particles increases, until it wholly predominates over the repulsive force.* The atoms of hydrogen, nitrogen, oxygen and light carburetted hydrogen, have a large amount of *caloric* around them in proportion to their size; the consequence of which is, that the thermo-repulsive force greatly predominates. But when they are made to combine with each other chemically, or with carbon, phosphorus, sulphur, chlorine, &c., making gases of greater specific gravity and atomic weight, their elastic force is diminished, even in cases where little or no caloric is given out, as in the combinations of nitrogen and hydrogen, nitrogen and oxygen, nitrogen and carbon, with numerous others, formed of these and of sulphur, phosphorus, &c.

It has long been a matter of controversy whether the oxygen and nitrogen of the atmosphere exist in a state of mechanical mixture, as maintained by Dr. Dalton, or in a state of chemical combination. Dr. Thomson has recently maintained that it is composed of 80 parts nitrogen to 20 of oxygen, constituting definite proportions by volume; therefore, that it is a chemical compound. (*Records of Science*, vol. iii. p. 184.) This hypothesis does not accord with the best-established facts connected with the theory of volumes. For example, in all the combinations of oxygen and nitrogen that are known to be chemical, there is a reduction of volume and elasticity, except in the case of the binoxide, which is composed of equal volumes of

each. Besides, it would seem to be a general law, that, whenever unequal volumes of gases unite chemically, there is a diminution of their aggregate volume. This view is supported by the facts presented in Table III., *page* 76; while it is evident from the foregoing details, that all such chemical combinations are attended with a reduction of elasticity. But the volume and elastic force of oxygen and nitrogen, as they exist in atmospheric air, are the same as when in a separate state, which would seem to demonstrate, that air is a mechanical mixture, and not a chemical combination.

The elastic force of light carburetted hydrogen is less than that of simple hydrogen. When Mr. Perkins submitted it to mechanical pressure, he found that it began to liquefy under a force equal to the weight of 40 atmospheres; and that under a pressure of 1200 atmospheres it was perfectly condensed into the liquid form. Being composed of two atoms hydrogen to one of carbon, its specific gravity and atomic weight are to hydrogen in the ratio of eight to one.

When two atoms or volumes of carbon unite with two of hydrogen, they form bicarburetted hydrogen, (olefiant gas,) the specific gravity and atomic weight of which are 14, compared with hydrogen as unity. During this combination, the four volumes of hydrogen and carbon contract into one volume, the elastic force of which is much less than that of carburetted hydrogen; yet we have seen from the experiments of Dulong and Hess, that equal volumes of carburetted hydrogen give out three, and olefiant gas five times more caloric than simple hydrogen; while the vapours

of ether and turpentine afford from ten to twenty times more. Why then is their elastic force so much less at the same temperature? The only answer to this question is, that the repulsive force of caloric is counteracted by its attraction for the larger particles of the compound gases by which their elements are chemically united, producing definite contraction of volume. If such were not the case, their elastic force would be greater than that of hydrogen, in proportion to the greater amount of caloric they contain.

This inference is rigorous; and it is so important in its bearing upon the whole science of chemistry and physics, that I have dwelt upon it even at the hazard of repetition, with a hope that by presenting the operation of the same principle in different points of view, it might be rendered clear and intelligible to the most ordinary capacity. It explains why the expansive force of steam is greater, other things being equal, in proportion as the quantity of water employed in its generation is less; a thorough comprehension of which is destined to effect an immense saving of fuel.

The law by which the repulsive force of caloric is counteracted by its affinity for ponderable matter, is still more strikingly illustrated by the changes which are produced in the statical and dynamical properties of hydrogen and sulphur, oxygen and nitrogen, chlorine and nitrogen, with some others.

It was before noticed that the specific gravity of sulphur vapour, as determined by the experiments of Mitscherlich, is 6·666, which is about 96 times the specific gravity of hydrogen gas; and it requires a temperature of about 640° F. to maintain it in the

gaseous form, when not united with other bodies. But if brought into contact with hydrogen gas, or if sulphur be volatilized in contact with hydrogen, they both undergo remarkable changes.

In the first place, 16 parts by weight of sulphur combine chemically with one of hydrogen, forming hydrosulphuric acid, (sulphuretted hydrogen,) the specific gravity of which is 17 times that of hydrogen, and its elastic force comparatively low. The particles of sulphur, which are 16 times larger than those of hydrogen, receive from the latter gas a portion of the ether that encompassed its atoms, by which they are intimately united.

During this process, the particles of sulphur acquire a much greater repulsive force, and are removed so much farther from each other, that they occupy six times the volume which they did in the form of vapour, before combining with the hydrogen.

The elastic force of the hydrogen is so far diminished by uniting with sulphur, atom to atom, that sulphuretted hydrogen may be liquefied by a pressure equal to 17 atmospheres, at the temperature of 50°, according to the experiments of Faraday. It was afterwards discovered by Davy, that when reduced to the temperature of 3° F., the elastic force of its vapour was equal to the pressure of only 14 atmospheres.

When two atoms of sulphur 32, combine with one atom of hydrogen, the resulting compound is a brownish yellow and dense liquid, (specific gravity 1·769,) somewhat acid, of an oily and tenacious cônsistence. If submitted to very low temperatures, its specific gravity and cohesion are still further augmented, when

it becomes an exceedingly firm solid, like butter, tallow and innumerable other fluids and semifluids under the same circumstances. When an atom of sulphur 16, combines with two atoms of oxygen 16; or when sulphur vapour combines with oxygen, the elasticity of the latter is nearly destroyed; while the atoms of sulphur are removed farther from each other, and acquire a degree of elasticity at the expense of the oxygen: for the specific gravity of the sulphurous acid thus formed is only 2·222, which is just one-third of 6·666, that of the sulphur vapour, in agreement with the law of multiples, which may be traced in all the contractions and expansions that gaseous bodies undergo during combination and decomposition.

According to the experiments of Faraday, sulphurous acid may be liquefied by a pressure equal to two atmospheres, at the temperature of 45°; and by cold without pressure, according to the experiments of Bussy and others. It must be observed, however, that during the combinations of oxygen and sulphur, a portion of caloric is given out, as in the union of oxygen and hydrogen to form aqueous vapour; which is one cause of the diminished elasticity in sulphurous and sulphuric acids.

The same order of phenomena which marks the union of sulphur and hydrogen, is exhibited during the combination of phosphorus, iodine, bromine, selenium, tellurium, &c., in the state of vapour, with hydrogen and other permanent gases. The volume and elasticity of these dense vapours are augmented by receiving from the lighter gases a portion of the principle on which their volume, &c. depend, during the very act of combining.

The specific gravity of phosphorous vapour is 4·444, at the temperature of 550° F.; or about 64 times the specific gravity of hydrogen. But when it combines with hydrogen, it becomes highly elastic, and its particles occupy four times their former space, as in phosphuretted hydrogen, the specific gravity of which is only 17 times that of hydrogen.

The specific gravity of iodine vapour is 8·75 at the temperature of 347° F. When it unites with hydrogen, atom to atom, (that is, in the ratio of 126 by weight to one of hydrogen,) hydriodic acid is formed, the specific gravity of which is 4·386, or about one-half that of iodine vapour, in accordance with the law of multiples as shown in hydrochloric acid, ammonia, &c.

The same principle applies to the various combinations of hydrogen with the vapours of bromine, cyanogen, arsenic and mercury, as in its combinations with the vapours of sulphur, iodine, &c. (See *Table III.*, of the preceding Chapter.)

When three, four or five volumes of oxygen combine with two of nitrogen, the aggregate bulk and elastic force of the resulting compounds diminish with every additional dose of oxygen. Nitrous acid may be liquefied by moderate degrees of cold without pressure. Yet it contains nearly if not quite as much caloric as the oxygen and nitrogen of which it is composed, when in a separate state. It was long ago observed by Higgins, that during the combinations of oxygen with nitrogen, no caloric is given out; and that during the union of nitric acid with potassa, very little heat is disengaged.

That such is really the case would appear from the immense quantity and intensity of the heat evolved by the deflagration of nitrate of potassa with charcoal and sulphur, as in gunpowder and other deflagrating mixtures formed of nitre, phosphorus, naphtha, turpentine and various combustibles. It is generally known, that during their combustion with nitre, nearly as much caloric is given out, even in vacuo, as when they are burnt in atmospheric oxygen; which proves that a large amount of caloric is concentrated around the particles of the nitric acid of the saltpetre, and set at liberty during its decomposition.

PHILOSOPHY OF EXPLOSION OR DETONATION.

Immediately connected with the foregoing theory, is the rationale of explosion; a phenomenon which has never been explained, and has been often adduced as an argument against the materiality of caloric. It has been supposed that the quantity of heat given out during explosion, and that which is requisite to convert gunpowder into the gaseous state, could not have existed in a state of combination with its particles.

This error has arisen from not attending to the law by which *caloric is concentrated around the atoms of ponderable matter*, with a force that increases in proportion to the augmentation of their size, other things being equal; and by which its self-repulsive force is counteracted. I have shown that the elastic force of nitrogen is equal to a pressure of 1200 atmospheres; but that when five volumes of oxygen are combined

with two of nitrogen, they contract. into two volumes of nitric acid, without any material loss of caloric; and that when five atoms of oxygen 40, unite with an atom of nitrogen 14, they form compound molecules of nitric acid, the weight of which is 54, compared with hydrogen one: from which, and the foregoing facts, we are bound to infer, that the repulsive force of the ether which surrounded the atoms of oxygen and nitrogen, is counteracted and nearly vanquished by the *attraction* of caloric for the larger particles of the compound.*

By referring to Table I. page 67, we perceive that the atomic weight of potassa is 48, compared with hydrogen as unity. One atom of nitric acid 54, combines with one of potassa 48, making compound molecules of nitrate of potassa, the weight of which is 102; and the attraction of caloric for which, so much exceeds its idio-repulsive force, that they are aggregated into a crystalline solid of a prismatic form. Let us then

* It was before observed that when two volumes of hydrogen combine with one of oxygen to form water, an immense quantity of caloric is disengaged, and that the aëriform state is merged into the liquid state. But as the combinations of oxygen and nitrogen retain nearly the same amount of caloric as their constituents, they also retain the gaseous form at ordinary temperatures, though their aggregate bulk and elasticity are greatly diminished. This fact is very remarkable; for the particles of nitric acid are larger than those of water in the ratio of 54 to nine; or six to one. It is difficult to conceive why they retain the elastic state, unless they retain around them a large amount of the same ethereal principle which belongs to their elementary constituents; whereas oxygen and hydrogen give out a large proportion of it on combining tó form water.

examine the composition of gunpowder. It consists of one atom of nitre 102, one of sulphur 16, and three of carbon 18, in a state of intimate mixture. When perfectly dry, and heat is applied, the nitre is decomposed into its original constituents, with a tremendous force of explosion, which is owing principally to the elastic force of the nitrogen, on being released from its combination with the oxygen and potassa of the nitre. During this rapid process, two atoms of oxygen combine with one of sulphur, making sulphurous acid gas; while the other three atoms of oxygen that existed in the nitric acid, combine with three atoms of carbon; forming carbonic oxide and carbonic acid. But as the elastic force of these gases is comparatively low, the explosive action must depend chiefly on the sudden expansion of nitrogen on assuming the gaseous state. The whole is nothing but an instantaneous combustion of sulphur and charcoal, accompanied by the disengagement of heat and light as in ordinary combustion, and by the sudden liberation of nitrogen, which, in the separate state, exerts an elastic force equal to a pressure of 16,800 lbs. to the square inch. The force is also greatly increased by the caloric given out during the formation of carbonic oxide, carbonic acid and sulphurous acid.

This is a most instructive exemplification of the law by which caloric exerts two opposite forces; the one or the other prevailing according to circumstances. At ordinary temperatures, the compound particles of nitre, sulphur and carbon retain *caloric* around them with a greater force than that by which it repels its own particles; but when they are decomposed and

subdivided into smaller particles, the repulsive force of their ethereal constituent acquires the ascendency.

The same principle applies to all fulminating compounds, whether solid, liquid or aëriform, as chlorate of potassa; fulminating mercury, gold, silver, platinum, &c.; iodide and chloride of nitrogen, protoxide and peroxide of chlorine, and some other detonating compounds, all of which are attended with expansion of volume and disengagement of heat during their decomposition.

Chlorate of potassa is composed of chloric acid and potassa. When triturated with sulphur, phosphorus or charcoal, it forms a deflagrating compound. In the ratio of three parts of the chlorate to one of sulphur, it explodes violently when gently heated, or struck with a hammer. If two grains of the chlorate be mixed with one of phosphorus, in a bit of paper, and struck with a hammer upon an anvil, there is a violent explosion. The chloric acid is decomposed in all such cases; the chlorine unites with the combustible, and the oxygen being liberated expands with a force proportional to its elasticity in the gaseous state, for the same reason that nitrogen expands when separated from the nitre of gunpowder.

It is by contemplating the elastic force of caloric in oxygen and nitrogen, while in the state of simple gases, that we are enabled to appreciate the stupendous force of attraction by which it is concentrated around the molecules of ponderable matter. If we take the experimental result of Rumford, that 15 grains of gunpowder expand when ignited, with a force equal to the pressure of 400,000 lbs. or 200 tons weight, it fol-

lows from a simple calculation, that the elastic force of caloric in one pound of gunpowder, is equal to the pressure of 102,400 tons weight. This enormous force is restrained by the attraction of caloric for the molecules of gunpowder and all detonating compounds that contain nitrogen, until decomposed, when it expands with an energy far surpassing the most elastic steam, for the same reason that the oxygen of chlorates expands with irresistible violence when decomposed.

Of all the detonating compounds, chloride of nitrogen affords the most simple and striking example of the opposite effects exerted by caloric under different circumstances. It is composed of three volumes of chlorine to two of nitrogen, which, on uniting, condense into a volatile, oily liquid, the specific gravity of which is 1·6. While its elements are united, the elastic force of the caloric in nitrogen is restrained by the greater force with which it combines with the atoms of chlorine. These two opposite forces are so nearly balanced, that by adding a small amount of caloric to the chloride it is decomposed, the nitrogen expanding with its accustomed force when reduced to the separate state. The chlorine also assumes the gaseous state, with evolution of heat and light. The chloride may be decomposed by the volatile oils, naphtha, phosphorus and various other combustibles, which unite with chlorine, when it explodes as when heated to 212° F.

Euchlorine, (chlorochloric acid,) peroxide of chlorine and deutoxide of hydrogen, also expand with explosion and evolution of heat and light on being decomposed,

because the *affinity* of caloric for their particles is diminished by reducing their size. The more completely ponderable matter is divided, the less tendency has caloric to concentrate around its particles. Hence, the quantity of caloric given out during ordinary combustion, other things being equal, is in proportion as the decomposition is complete. When coal or wood is but partially decomposed, gross vapours are formed, constituting smoke, the particles of which are much larger than those of flame, and which retain and carry off a considerable amount of the caloric that is given out by radiation when the combustion is perfect.

The whole theory of combustion is founded on the various degrees of force with which caloric attracts the particles of ponderable matter under different circumstances. It is more concentrated around the atoms of dense, than of light gases and vapours; and greatly more so around the larger compound particles of liquids and solids. In short, all the absorptions of caloric by which it combines with and becomes latent in ponderable matter, result from this affinity; while the *escape of caloric* during combustion or deflagration, results from the diminution of that affinity; for the same reason that the volume and elastic force of hydrogen and nitrogen greatly augment on the decomposition of ammonia.

There is nothing more clearly demonstrable in science, than that all the caloric evolved during the decomposition of ponderable matter, whether solid, liquid or gaseous, is only a liberation of what was previously concentrated around the atoms of the materials employed. When the particles of solids are

separated and subdivided by friction or collision, a portion of their concentrated caloric is disengaged, producing incandescent sparks, or streams of fire.

A machine is exhibited at the Hall of Practical Science in London, which illustrates the manner in which solid bodies may be reduced to a state of incandescence by mechanical friction. A circular plate of soft iron is made to revolve at the rate of 5000 times per minute, when the hardest steel on being applied to its edge is cut through rapidly, and reduced to inconceivably small particles, which are expanded by the caloric thus liberated, into a shower of metallic flame and sparks. This kind of ignition proceeds equally well in vacuo as in the atmosphere.

Mr. Brande observes, in the last edition of his *Manual of Chemistry*, page 390, that the existence of nitrogen in nearly all the powerfully detonating bodies, is a singular fact; and that explosion must remain unexplained until we ascertain the cause of the detonating power of such compounds. He also adds, that at present *the phenomena are at variance with the usual explanation of the evolution of heat and light during combustion, which have been supposed to be the result of union and condensation, instead of expansion and decomposition.*

The truth is, that in a large majority of cases, combustion, as well as explosion, is attended with expansion of the materials employed. Lavoisier, who maintained that *gaseous oxygen* was the source of heat and light in all cases of combustion, supposed that it was always condensed on combining with combustibles. This partial view of the subject has been

incorporated with so many works on Chemistry and Natural Philosophy, that it has become a very general opinion, that oxygen is the only supporter of combustion, and the source of heat and light, instead of the bodies with which it unites.

We have already seen, that during the combination of oxygen with hydrogen, they are both condensed into the liquid state; which condensation is attended with the evolution of caloric and light. But a large proportion of the caloric thus given out is disengaged from the hydrogen, which is therefore as much a supporter of combustion as the oxygen.

Oxygen is also condensed, and even solidified on combining with metals during their combustion in it, by which they are converted into oxides. In such cases, it is doubtless the principal source of caloric. It is however not the only supporter of metallic combustion; for cyanogen, chlorine, bromine, iodine, sulphur, phosphorus, and some other solid bodies, unite rapidly with metals when they are heated together, with evolution of heat and flame.

The combustion of carbon, sulphur and phosphorus in oxygen gas, is attended with intense heat; yet they are greatly expanded without any condensation of the oxygen: for the carbonic, sulphurous and phosphoric acids produced, have the same volume as that of the oxygen.

During the combustion of ether, alcohol, oils, resins, wood, coal and other inflammable bodies in oxygen, the volume of the gaseous products exceeds that of the oxygen; yet the process is attended with the production of immense quantities of heat and light.

There is a mixture prepared at the Military Academy at Woolwich, called the Carcass composition, that burns with great violence somewhat like the detonating compounds, which cannot be quenched with water, and has been supposed to resemble the Greek fire.

I am indebted to Dr. Faraday for the following mode of preparing it:—

	lb.	oz.
Nitrate of potassa	6	4
Sulphur	2	8
Powdered antimony	0	10
Powdered resin	1	14
Tallow	0	10
Venice turpentine	0	10

The resin, tallow and turpentine, are melted together. The sulphur and nitre are then added, being kept hot all the time and well stirred about. The powdered antimony is then added and worked well in it, when it may be formed into the shape required.

The combustion of this mixture is truly terrific, and the quantity of heat evolved enormous. It also goes on in vacuo as well as in the air, which is true of all deflagrating and detonating compounds. All such combustions are attended throughout with *expansion* of the burning bodies instead of condensation.

The explosive power of gunpowder may be lessened by augmenting the proportions of charcoal and sulphur. Fuses, which burn with a gradual or continuous deflagration, are composed in the ratio of

	lb.	oz.
Nitre	4	4
Sulphur	1	0
Common gunpowder ground into meal	1	12

From the foregoing facts and observations, we perceive how partial and erroneous is the prevalent notion, that under all circumstances caloric is a repulsive agent. We find that the caloric of explosion, like that of ordinary combustion, is only a liberation of what was previously concentrated around the particles of ponderable matter, and diffused during its dissolution.

Such is the beautiful simplicity of nature, that a clear comprehension of the law by which the molecules of a salt are aggregated and dissolved, affords a miniature representation of the mechanism by which all the phenomena of nature are carried on, from that of planetary motion to the no less important transformations of chemistry.

It has been shown, that cold, or the abstraction of caloric, produces the same effect on gases as mechanical pressure; that is, it diminishes their volumes, and condenses them into liquids or solids; which is effected by lessening the ratio of ethereal or elastic matter, while the quantity of ponderable matter remains the same. If we suppose that the repulsive force of this ether in hydrogen is equal to the weight of 2000 atmospheres, it must combine with the atoms of sulphur and other bodies with a still greater force, for we have seen that when one atom of sulphur combines with one of hydrogen, the resulting compound, sulphuretted hydrogen, may be liquefied by a pressure equal to 17 atmospheres at 60° F.; and the bisulphuretted hydrogen becomes liquid, or semi-solid, without any pressure.

By the affinity of caloric for ponderable matter its atoms are approximated and held together: by its

elastic or self-repelling property, it separates them from each other, as in vapourization, explosion and all decompositions. The fact that Philosophers have overlooked this affinity by which caloric is concentrated around the particles of liquids and solids, resolves the problem of contradictions by which the theory of caloric has been so long perplexed, and explains why many have doubted its materiality; why the phenomena of combustion, explosion, cohesion and chemical affinity have not been understood.

Thus we perceive, that caloric is the cause of repulsion in steam and all gases; in vapourization, combustion, and the expansive force of detonating compounds: and that this elastic force is counteracted and diminished, or vanquished by its affinity for inert matter. This doctrine throws a clear and full light on all the powers, motions, combinations and decompositions of the elements by which we are surrounded and sustained; and, when perfectly unfolded in all its relations, will be found to furnish a simple and rational interpretation of innumerable phenomena that have never been fully explained.

CONSTITUTION OF LIQUIDS.

It has been shown in the preceding chapter, that there is an intimate relation between the elastic force of gases, and the proportions of ether which surround their atoms; that hydrogen contains a larger amount of caloric, in proportion to the quantity of ponderable matter, than any other known body, and possesses a corresponding degree of expansive force; but that

when it unites chemically with oxygen, it gives out a large proportion of caloric, by which its volume and elasticity are diminished. It has also been shown that, other things being equal, the elastic force of all gaseous bodies is in proportion to the amount of caloric which is combined with any given quantity of ponderable matter.

I now proceed to show, that the lightest and most volatile liquids are composed of elements which contain the largest proportion of caloric around their atoms. I am not aware that any one has attempted to explain why liquids differ so greatly in their volatility: Newton referred it to their smallness; Boyle supposed that their tenacity was owing to the grossness of their particles,* which are nearly the same. But it is now well known that the proximate atoms of water are less than those of alcohol, ether and various other liquids that are more elastic and volatile at the same temperatures. The atoms of nitrous and nitric acids, of sulphuretted and phosphuretted hydrogen, of chlorine, hydrochloric acid and many other gaseous bodies, are larger than those of carbon, sulphur, phosphorus, silicium, calcium, &c. Yet the former are much more volatile and elastic than the latter. The atoms of etherine, sulphurous acid, muriatic ether, (which is composed of etherine and hydrochloric acid,)

* Lucretius observes that light passes through scraped horn, which wine and water will not do, because the particles of the latter are too large; but that water and wine percolate strainers more readily than oils, because the latter are composed of *larger particles*, or of *particles that are hooked*. (*De Naturâ Rerum*, Book II.)

protoxide of chlorine, &c., are larger than those of water or hydrocyanic acid, the elasticity of which is much inferior.

Such facts prove conclusively, that the elastic force of gases and liquids is not determined alone by the size of their proximate particles, but by their relations to a self-repelling fluid.

There is a class of liquids which are composed chiefly of hydrogen and carbon, that seem to form a connecting link between gases and more fixed bodies. They are generally much lighter than water, and exceedingly volatile. Such are etherine, spirit of gum elastic and naphtha. Ether, alcohol, pyro-acetic spirit, acetic ether, and most of the essential oils, which are composed of carbon and hydrogen united with small proportions of oxygen, are lighter than water, and some of them highly volatile. There are also a few combinations of hydrogen and carbon with nitrogen, chlorine and even iodine, that are very volatile, as nitrous ether, hydrocyanic acid, muriatic and hydriodic ethers. There cannot be a doubt that all such liquids owe their volatility to the same cause which determines the elastic force of gases. For we find, that etherine, the lightest of them all, boils or expands rapidly into the gaseous state, under the pressure of the atmosphere, below 32°. Common ether boils at 96°, muriatic ether at 60°, nitrous ether at 60°, acetic ether at 105°, and alcohol at 173°.* But when the pressure of the at-

* With a view of ascertaining how far the rationale of such phenomena had occupied the attention of philosophers, I took an opportunity of asking a distinguished professor of chemistry why ether and alcohol were more volatile than water: to which he re-

mosphere is removed, as under an exhausted receiver, the elastic force of the caloric which surrounds their particles expands them rapidly into vapour at 145° below their boiling points under the pressure of the atmosphere. In all such cases, liquids are expanded into the gaseous state, by the elastic force of their constituent caloric, which is thus diffused and carried off, by which intense cold is produced. In vacuo, pure ether is rapidly expanded into vapour at —46°, alcohol at 28°, and water at 67°; from which it follows, that they are all elastic fluids like gases, but in a less degree; and that if their elasticity were not restrained by the pressure of the atmosphere, they would boil at ordinary temperatures, until the process were checked by the pressure of their own atmospheres.

By reference to a subsequent table, it will be seen that ether is composed of five atoms of hydrogen, four of carbon, and one of oxygen; and that alcohol is composed of the same substance, united with one particle of water. Hence the difference between their specific gravities and boiling points; the specific gravity of pure ether being about ·700, and that of alcohol ·794, compared with water 1000, which congeals at 32° F.; while ether and alcohol are exceedingly difficult to congeal.*

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plied that he did not know, unless it were owing to the smallness of their cohesion. And Dr. Young tells us, that "the weakness of cohesion in fluids is owing to the *mobility* of their particles." (*Lectures on Nat. Philos.*, vol. i., p. 620.) The truth is, that our books abound with such definitions.

* It has been said that alcohol was frozen by Hutton; and Fourcroy supposed that he had frozen ether at —46°. But neither Thenard nor Bussy were able to congeal it: from which it is pro-

That light and volatile liquids contain more caloric than water and some others which are more dense and tenacious, might be inferred from the large amount of hydrogen which they contain, and from their highly combustible property.

It has been often stated gravely by chemical writers, that cold results from evaporation, *because vapours have a greater capacity for caloric than the liquids from which they are formed.* But this does not explain how liquids are converted into vapour. The coldness results from the elastic force of their constituent caloric, by which they are expanded over a larger space; yet without its being separated from their particles and radiated, as during combustion.

When an open vessel of water is placed over a fire, its temperature never rises above 212° F., however hot the fire may be; because at 212°, the elastic force of caloric in water overcomes the pressure of the atmosphere, and expands it into steam, the bulk of which is 1720 times that of water. But when water is enclosed in a strong vessel like Papin's digester, and prevented from expanding into steam, its temperature rises to 500° or more. If a vessel could be obtained strong enough, water might be made red hot; and if again permitted to expand, its temperature would im-

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bable, as observed by Mr. Brande, that the ether employed by Fourcroy was not pure. It is now certain, however, from the experiments of Thilorier, that both may be congealed.

When alcohol and water are mixed, they combine chemically with diminution of their aggregate volume and disengagement of heat. Proof spirit is composed of about equal weights of each, the specific gravity of which should be ·916.

mediately fall in proportion to the diffusion; and so of all other vapours.

The production of cold during the exhaustion of a receiver, as reported by Leslie and Dalton, is referable to the same cause, and not *to an increase of capacity for caloric in rarefied air*, as they supposed. That is, a large proportion of caloric is carried off in combination with the air which is pumped out; so that what remains is greatly diffused by virtue of its elasticity, producing a corresponding reduction of temperature. When carbonic acid, ammonia, cyanogen, chlorine and other elastic fluids are converted into the liquid or solid state by pressure, a still greater reduction of temperature results from their sudden expansion on removing the pressure.

M. Thilorier has recently invented an apparatus by which he can form large quantities of liquid carbonic acid, the rapid expansion of which, when released from pressure, causes a reduction of temperature equal to 164° below the freezing point of water, by which the liquid carbonic acid is converted into white solid lumps. When alcohol was poured upon them, it was immediately converted into a hard, brittle ice; while ether was congealed to the consistence of sodden snow.* M. Bussy has also congealed alcohol (sp. gr. ·850) by the evaporation of liquid sulphurous acid in vacuo. (*Ann. de Chim.* for May, 1824.)

* Carbonic acid is procured in the liquid state by adding together in a close strong iron vessel, two pounds bicarbonate of soda, three pints of water at 100° and eight ounces of sulphuric acid.

When ether is dropped upon the hand, the caloric of the living body expands it into vapour, and is carried off in an invisible form, causing coldness. In the same way, the caloric of the solar rays is continually expanding the water of the earth into vapour, and diffusing it through the atmosphere, (to be given out in colder regions,) by which the sultry heats of summer are diminished.

That all odoriferous emanations consist of extremely minute particles of bodies diffused through the atmosphere by caloric, need scarcely be mentioned; being obvious from the fact, that at very low temperatures they are not produced. Excessive cold puts a stop to all volatilization and decomposition of matter.

That the numerous facts connected with the constitution of different liquids may be the more readily understood, I have presented them in a tabular form.

The first column of the first table exhibits the formulæ of the various compound liquids; the second represents their united equivalents, compared with hydrogen as unity. The third column gives the specific gravity of the liquids, compared with water 1000, —and the fourth, their boiling points. The remaining numbers give the relative proportions of their constituents in the 100 parts by weight, as derived from the best analyses of modern chemists. By inspecting the first table, it appears that all the most spirituous and volatile liquids contain large proportions of hydrogen and carbon; most of which are lighter than water, and boil at lower temperatures.

TABLE I.

Representing the Atomic Constitution, Specific Gravity and Boiling Points of various Volatile Liquids, &c.

	Formulæ.	Proximate atom.	Sp. Gr.	Boiling point.	Relative Proportions by Weight in 100 Parts.				
					C.	H.	O.	N.	Parts.
Etherine.........	C_4H_4	28	·627	82°	85·15	14·25	....	....	100
Sp. of caoutch...	CH	....	·640	....	85·71	14·29	....	....	100
Mur. ether.......	C_4H_5Cl	65	·874	60°	36·9	7·7	55·4 Cl.	....	100
Nitrous ether....	$C_4H_5NO_4$	70	·880	70°	32·00	6·67	42·67	18·66	100
Acetic ether	$C_8H_8O_4$	88	....	105°	54 55	9·09	36·86	....	100
Ess. of lemon....	C_5H_4	34	·847	....	88·1	11·9	...	....	100
Hydrocy. acid...	C_2HN	27	·705	80°	44·4	3·7	....	51·8	100
Ether..............	C_4H_5O	37	·700	96°	64·87	13·51	21·62	....	100
Naphtha..........	C_6H_5	86	·750	160°	87·75	12·25	....	....	100
Bicarb. of hyd...	C_6H_7	39	·850	186°	66·66	33·33	....	....	100
Paraffine.........	$C_{20}H_{21}$	129	·870	120°	85·02	14·98	....	....	100
Pyro-acetic sp ..	C_3H_3O	29	·792	132°	62·08	10·38	27·59	....	100
Pyroxilic spirit	C_2H_2O	23	·804	150°	52·17	13·05	34·78	....	100
Hydriod. ether..	C_4H_5I	154	1·92	148°	15·60	3·15	81·25 I	....	100
Hydrocy. ether..	C_4H_5Cy	55	·700	180°	65·5	9·1	....	25·4	100
Alcohol..........	$C_4H_6O_2$	46	·794	173°	52·17	13·51	34·32	....	100
Bisul. of carb....	CS_2	38	1·272	102°	15·79	84·21 S	....	....	100
Chl. of sulphur..	S_2Cl	68	1·687	280°	52·94 S	47·06 Cl	....	....	100
Chl. of nitr.......	NCl_3	122	1·6	212°	88·5 Cl	....	....	11·5	100
Iodide of nitr....	NI_3	392	....	....	94·4 I	....	....	3·6	100
N. acid, concen	$\dddot{N}HO$	63	1·5	184°	91· $\dddot{N}$	1·58	76·20	22·22	100
Mu. acid, conc...	$HClAq_6$	91	1·2	112°	38 48Cl	7·60	53·83	....	100
Hydriodic acid..	HI	127	1·7	260°	99·21 I	·79	....	....	100
Acetic acid	$C_4H_4O_4$	60	1·062	....	42·	6·66	53·32	....	100
Cyanic acid......	CyO	34	....	....	32·5	41·10	....	28·7	100
Sul. cyan. acid..	CyS_2	59	1·022	217°	45 8Cy	54·2 S	....	....	100
Perchloric acid..	ClO_7	92	1·6	392°	39·13Cl	....	60·87	....	100
Sul. acid, conc...	$\dddot{S}HO$	49	1·845	620°	24·6 S	1·7	73·7	....	100
Water.............	HO	9	1·000	212°	....	11·9	88·1	....	100

TABLE II.

Representing the ultimate Constitution of the Volatile and Fixed Oils, with some other Compounds,—their Specific Gravity, Boiling Point, &c.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Proximate atom.	Sp. Gr.	Boiling point.	Relative Proportions by Weight in 100 Parts. C.	H.	O.	N.	Parts.
Camphene......	C_{10}	H_8	...	...	68	·860	812°	88·1	11·9	...	...	100
Oil of Anise......	C_{10}	H_5	O	...	72	·985	...	81·4	7·98	10·62	...	100
" Peppermint.	C_{10}	H_{10}	O	...	78	·920	...	77·8	12·6	10·1	—	100
" Lavender.....	...	...	...	...	...	·877	397°	...	...	...	...	...
" Rosemary...	...	...	...	...	...	·890	365°	...	...	...	...	...
" Camphor	...	...	...	...	...	·988	...	79·28	10·86	10·36	...	100
" Caraway	...	...	...	...	...	·940	...	...	...	...	...	...
" Juniper......	...	...	...	...	...	·911	...	...	...	...	...	...
" Cinnamon ...	...	...	...	...	...	1·350	...	...	...	...	...	...
" Sassafras	...	...	...	...	...	1·094	...	...	...	...	...	...
Benzule..	C_{14}	H_5	O_2	...	105	...	...	...	...	..	...	...
Naphthalin	C_{10}	H_4	...	...	64	...	410°	89·00	11·00	...	...	100
Paranaphthal....	C_{15}	H_6	...	...	94	...	572°	...	...	...	...	...
Creosote	C_{14}	H_9	O_2	..	109	1·037	397°	72·42	8·12	14·46	...	...
Petrolene.........	C_{20}	H_{16}	...	..	128	...	586°	88·5	11·5	...	...	100
Oil of bitr. alm.	C_{14}	H_6	O_2	...	106	1·043	...	79·56	5·56	14 88	...	100
" Cloves........	C_{20}	H_{13}	O_5	...	178	...	...	70·02	7·42	22·56	...	100
" Spermaceti..	...	...	...	...	...	...	...	79·5	11·6	8 9	...	100
Hogslard	...	...	...	...	...	...	...	79·098	11·146	9·756	...	100
Tallow.............	...	...	...	...	...	...	...	78·996	11·700	9·304	...	100
Castor Oil........	...	...	...	...	...	...	...	74·000	10·29	15·71	...	100
Linseed Oil	...	...	...	...	...	...	...	76·01	11·35	12·63	...	100
Olive Oil	...	...	...	...	...	...	600°	77·21	13·36	9 42	...	100
Resin	...	...	...	...	...	...	...	75·94	10·71	13·33	...	100
Beeswax	...	...		...	...	...	...	80·60	11·47	7·93	...	100
Camphor	C_{10}	H_8	O	...	76	·988	400°	...	...	...	...	...
Sugar.............	C_{12}	H_{11}	O_{11}	...	171	...	...	42·1	6·4	51·5	...	100
Gum...............	C_{12}	H_{10}	O_{10}	...	162	...	...	43·75	6·77	49·68	...	100
Starch	C_{12}	H_{10}	O_{10}	...	162	...	...	43·75	6·77	49·68	...	100
Gluten	...	...	..	...	...	...	...	57·7	7·8	22·00	14·5	100
Lignin	C_{12}	H_{10}	O_{10}	...	162	...	...	43·75	6·77	49·68	...	100
Blood	C_{48}	H_{39}	O_{15}	N_6	585	...	...	...	...	...	..	...
Flesh	C_{48}	H_{39}	O_{15}	N_6	585	...	...	...	...	...	...	...
Protein...........	C_{48}	H_{36}	O_{17}	N_6	587	...	...	...	...	...	...	...

Naphtha is composed of five atoms hydrogen and six of carbon, or of 87·75 parts by weight of carbon, to 12·25 of hydrogen in the 100. It is also more dense than etherine, and less volatile. Hence it would seem, that the elasticity of etherine exceeds that of naphtha, for the same reason that the elastic force of olefiant gas is greater than that of etherine; or that the elasticity of hydrogen exceeds that of olefiant gas.

It has been found, that several of the essential oils are hydrocarbons, as the essence of turpentine, lemons, copaiva, bergamot and camphene, or camphogen; but that most of them are composed of hydrogen and carbon, united with oxygen; or that they are *oxides of hydrocarbons*, as they have been termed by Dumas.

The oil of mustard contains sulphur and nitrogen; the oil of bitter almonds also contains some nitrogen, according to Liebig and Wöhler. When perfectly pure, it is composed of one equivalent of benzoxyl and one of hydrogen, the proximate molecule of which is 106. But the molecular weights of the volatile oils have not been accurately ascertained, owing to the fact, that they do not combine with bases without decomposition. They are of a pungent aromatic taste and odour; and many of them pass into the form of vapour at the temperature of boiling water; but some of them require a much greater heat. Dumas observes, that their density is proportional to the quantity of oxygen they contain.

The specific gravity and chemical constitution of the fixed oils are nearly the same; yet they require a temperature of about 600° F. to volatilize them. Why, then, it may be naturally inquired, if they consist

chiefly of carbon and hydrogen, is their cohesion greater than that of ether, alcohol, water and the essential oils? The following facts may tend to throw some degree of light on this question.

By adverting to the second table, it will be found that *camphene*, or *camphogen*, is composed of $C_{10}H_8$, united into one compound particle, the weight of which is 68, compared with hydrogen: whereas, the essence of lemon is composed of C_5H_4, making a proximate particle equal to 34, or one-half that of camphene. The consequence of which is, that the latter is much more volatile than the former, though their specific gravities are nearly the same. Camphene requires a temperature of 312° F. to make it boil, while the essence of lemon is highly volatile like naphtha. Camphene is the principal ingredient in oil of turpentine and camphor, both of which are oxides of camphene. Common camphor is composed of one equivalent of camphene to one of oxygen. There is also an artificial camphor, composed of hydrochloric acid one equivalent, united with one of camphene; while three equivalents of water and one of camphene make the hydrate of camphene; and five atoms oxygen to one of camphene, camphoric acid. Petrolene, which is obtained from petroleum by distillation, is, according to Boussingault, composed of carbon and hydrogen in the same proportions as camphene; but its proximate particle being just double that of camphene, corresponding with the difference between the specific gravity of their vapours, it possesses the consistence of a fixed oil, requiring a temperature of 536° F. to convert it into vapour. The product (asphaltine)

which remains after the distillation, is still more tenacious.

Naphthalin is composed of $C_{10}H_4$ united into one equivalent 64. It is a highly tenacious liquid, requiring a temperature of 400° for its volatilization.

According to Dumas and Laurent, there is a combination of carbon and hydrogen in the ratio of $C_{15}H_4$ (equivalent 94) which has been called *paranaphthalin.* It is one of the last products from the distillation of coal-tar, and is less volatile than naphthalin. The atomic weight of sulphuric acid is 40, and that of naphthalin 64. When two equivalents of the former unite with two of the latter, the compound equivalent is 208 of sulphonaphthalic acid, (according to Faraday,) forming a hard and brittle solid, that is soluble in water, alcohol and oils.

Naphthalin also forms a dense and tenacious compound with chlorine. With cyanogen, sulphur, iodine, bromine, &c., it forms dense semi-liquids, the cohesion of which augments in proportion to the increased magnitude of their compound equivalents.

From the molecular constitution of camphene, oil of turpentine, cloves, peppermint, anise, naphthalin, &c., there can scarcely be a doubt that their cohesion, and that of the fixed oils, is greatly modified, if not wholly determined, by the number and relative proportions of elementary atoms which combine into complex molecules of larger size. Hence, etherine is more volatile than naphtha, and the latter than camphene. Camphene is more volatile than naphthalin, and the latter than paranaphthalin, although they are all composed of carbon and hydrogen. The equivalent of

camphene exceeds that of naphthalin, while the latter is less volatile; but this is owing to the fact, that camphene contains just double the ratio of hydrogen.

By looking over the preceding tables, we perceive that the most volatile liquids are composed largely of hydrogen and of other elastic gases; such as hydrochloric ether, nitrous ether, acetic ether, hydrocyanic and hydriodic ethers, chloride of nitrogen, nitric acid, (anhydrous,) pyroacetic spirit, &c.; all of which expand into the gaseous state at temperatures below 212° F., notwithstanding their proximate equivalents are large. But it was also shown, that carbon, phosphorus, sulphur, iodine, bromine, and even arsenic, may be converted into permanent gases by combining chemically with hydrogen; that they receive from it a portion of caloric by which their elastic force is increased, and that of the hydrogen diminished; that their volume and elasticity decrease in proportion to the size of their proximate particles, until they assume the liquid or solid form. The most singular circumstance connected with this subject is, that carbon should not be elastic at all temperatures, like oxygen, nitrogen, hydrogen and their combinations. Considering the large amount of caloric evolved during its combustion, there is something very mysterious about the fixedness of charcoal at high temperatures.

The whole theory of distillation and sublimation is founded on the different degrees of volatility in the various ingredients of solid and liquid bodies, from the rectification of the ethers, alcohol and the volatile oils, to the distillation of coal, by which its carbon, hydrogen and oxygen are volatilized in a state of carburetted

hydrogen, olefiant gas, carbonic oxide, &c., as in coal-gas.

That the *proximate molecules of the fixed oils*, such as olive oil, castor oil, spermaceti, lard, tallow, &c., are larger than those of the volatile oils, would appear from a variety of considerations:—

1. They are generally opaque, and many of them obtained by expression from the seeds of plants; from which it is probable that they contain a mixture of gross particles, united with more volatile particles; and that they differ from essential oils in a manner somewhat analogous to the difference between smoke, which is composed of gross vapours, and the pure gases, which are transparent and invisible.

2. In its ordinary state of impurity, oil of turpentine volatilizes slowly at 300° F., when a limpid oil passes over. At 360° it boils; but on losing its essential oil, it becomes more tenacious, and requires a temperature of 500° F. to make it boil; thus, passing from the state of a volatile to that of a fixed oil.

The oil of anise is composed of 10 atoms carbon, six of hydrogen and one of oxygen, making its proximate atom equal to 74; while the oil of peppermint consists of $C_{10}H_{10}O$, making its compound equivalent 78: so that in their atomic construction they resemble naphthalin, forming a medium between the more volatile oil of lemons, and those termed fixed.

According to Dumas, the oil of cloves is composed of 20 atoms carbon, to 13 of hydrogen and five of oxygen, making its proximate atom 173. It is accordingly very difficult to volatilize, like the fixed oils;

from which it is probable, that their atomic constitution is similar, and determines their tenacity.

When the volatile oils are exposed to the atmosphere, they absorb oxygen, by which they become resinous and concrete. The oil of turpentine is thus converted into rosin. By absorbing oxygen, the fixed oils become rancid; and much more rapidly in warm than cold weather; during which process, carbonic acid is produced, and heat evolved, as in fermentation. Hence, the spontaneous combustion of cotton goods which have imbibed oily matter. Again, the molecular equivalent of starch, sugar and gum, is 162, 171 and 162; while that of the animal tissues is 535, according to the lowest estimates. Hence, the great tenacity of muscular fibre, of tendons, ligaments, membranes, and the difficulty of volatilizing them; as in the case of starch, sugar and gum.

BOOK II.

CHAPTER I.

ON THE AGENCY OF CALORIC IN THE COHESION OF SOLIDS.

"Among learned men, it is no unusual or unheard-of arrogance, wilfully to reject opinions which they cannot shake."—BACON.

IT was long since observed by Lord Bacon, that the most important facts connected with the fundamental constitution of nature had been quite overlooked; such as "*the cause of heat and light, weight and density, hardness and softness, solidity and fluidity, fermentation and putrefaction, germination and organization.*" (*Novum Organum.*)

Although more than two centuries have elapsed since Bacon pointed out the radical defects of science, and the true mode of its regeneration, scarcely one of the above problems has been resolved in a satisfactory manner. Philosophers are still as much divided in regard to the nature of heat and light as they were in the time of Bacon, Galileo and Boyle; or the still more remote period of Plato and Aristotle.

Sir Isaac Newton devoted many years to the inves-

tigation of light, and really accomplished much toward an elucidation of its physical properties; but without ever having inquired into its connection with heat, or its wonderful agency in the work of the universe.

The same illustrious author resolved the cohesion of solids and the tendency of heavy bodies toward the centre of the earth into the same law which determines the aggregation of planets, and their revolutions around the sun; but he did not identify the *cause* of universal attraction with any known agent. In short, he did not distinctly unfold the fundamental principle of action in nature—of expansion and contraction, density and lightness, hardness and softness, solidity and fluidity, chemical union and decomposition. There is nothing more remarkable in the history of science, than that the phenomena of attraction should have been so far unfolded and generalized, without any definite knowledge of their cause. It would seem that one of the first inquiries of the philosopher ought to be, what is the agent or cause of force, by which the atoms of matter are held together? and that the most natural answer would be, that which surrounds and fills the spaces between them.

It can no longer be disguised, that in regard to the *cause* of cohesion, capillary attraction and gravitation, Sir Isaac Newton has expressed himself with so much ambiguity as to leave his followers in great doubt whether he had any settled opinion on the subject. In the third book of the *Principia*, he maintained that *universal space is a vacuum;* or *that it is void of all sensible matter*, and that *the ultimate particles of*

*bodies are endowed with inherent forces, or powers of attraction and repulsion.**

That he afterwards renounced the *vacuum of space* and the *self-motive power of atoms*, is evident from the scholium which he added to the second edition of the *Principia*, his letter to Boyle, and from the whole tenor of the *Opticks;* in each of which he maintains the existence of an exceedingly subtile, active and elastic ether, as pervading universal space and the pores of all bodies.

Considering the almost unbounded influence of Newton's authority on nearly all subjects connected with the science of nature, it is important that his real opinions should be distinctly understood. I shall, therefore, proceed to prove, by his own words, that he did not regard attraction as an ultimate law of nature, resulting from the inherent properties of atoms. In addition to the passages before quoted, in the first chapter of this work, he observes in the advertisement to the second edition of the *Opticks:* "to show that I do not take gravity for an essential property of bodies, I have added one question concerning its cause, choosing to propose it by way of question, because I am not satisfied about it for want of experiments."

* Such, however, is the blinding influence of custom and authority, that men who have never found any difficulty in admitting Sir I. Newton's *inherent powers of attraction and repulsion*, are yet startled at the inherent powers of caloric, or the doctrine that it is a self-active principle. The self-motive power of spirit was beautifully symbolized by the Greeks, who represented Psyche standing on a car which moved itself.

The same view is still further expanded in the third book of the *Opticks*, page 365. After observing that "all matter, even light, seems to be composed of exceedingly small, hard and unchangeable atoms, which in the densest bodies touch only in a few points," he adds: "how they can stick together so firmly as they do without the assistance of something which causes them to be attracted or pressed toward one another, is very difficult to conceive."* He remarks, in another passage, *page* 369, "there are agents in nature capable of causing the particles of matter to stick together by very strong attractions, and that it is the business of experimental philosophy to find them out." Yet it is an undoubted fact, that nearly all the most distinguished followers of Newton have represented him as teaching, that the sun operates upon the planets without any intervening mechanical medium; and that the matter of which planets is composed is held together by virtue of *inherent power*, or *innate forces*, which Newton expressly says that he could not conceive.

Again: in a letter to Dr. Bentley, he says: "You sometimes speak of gravity as essential to matter. Pray do not ascribe that notion to me; for the cause of gravity is what I do not pretend to know, and therefore would take more time to consider." (*Page* 20.) He adds, in another letter: "That gravity should be innate, inherent and essential to matter, so that one body may act upon another at a distance

* The same idea was advanced about 2000 years ago by Plato, who observes in the *Timæus*, that "it is impossible for two things alone to cohere, without the intervention of a third."

through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall into it." (*Third letter to Bentley*, page 26.)

It was truly observed by Bacon, that "the doctrines of great and original minds are often degenerated and embased by time; that while the lighter parts of their labours float down the stream of time, the weightier and more valuable frequently sink into oblivion."* This remark applies with great force to the misconception and perversion of the ancient systems of philosophy, the most important features of which are but vaguely and imperfectly comprehended by the moderns. When Greece was the centre of light and civilization to the whole world, nearly all her most distinguished sages maintained the existence of an igneous principle, which extended throughout the universe. This powerful and omnipresent agent was regarded by them as the life of nature, and the cause of all *concord* and *discord*, (by which they evidently meant attraction and repulsion,) by virtue of which the celestial bodies were preserved in their respective courses, and connected as by an invisible everlasting chain; and without which there could be no generation or dissolution of bodies.

Such were the opinions of Pythagoras, Parmenides, Democritus, Heraclitus, Plato and many others. Hippocrates termed it "a strong but invisible fire which

* Advancement of Learning.

rules all things without noise, and is never in repose; which actuates and animates the whole system of nature." Here is a definition of heat in accordance with the discoveries of Dr. Black, but still more comprehensive and important.

Like the ancient Greek philosophers, Bacon reduced all matter to two classes, *active* and *passive;* the first of which he describes as *rare, invisible and without weight, though a real and quantitative substance, pervading and filling the pores of all gross bodies.* I have already shown that this *active spirit,* to which Bacon referred all the motions and transformation of matter, is only another name for caloric. (See *page* 19.) But if this *pneumatical body* be the cause of all the changes of living and dead matter, it must be the cause of attraction as well as repulsion; of decomposition and recombination.

In his treatise on the *Wisdom of the Ancients,* Bacon further maintains that the attraction of matter was typified, among the early Greek philosophers and poets, by the elder Cupid, or principle of love; that it was the primitive cause of force, or the moving power of elementary atoms, which formed and organized the universe of things out of chaos. He adds, by way of commentary on this ancient allegory, that "there is doubtless a primary and universal law of nature, which regulates the circular revolutions of the celestial bodies, *and to which are owing all contraction and expansion of matter.*"

In the third book of his treatise on the *Advancement of Learning,* he says, that whoever shall attentively observe the appetences of matter, shall receive

clear information concerning celestial objects from things which are constantly seen around us; and that it is the object of science not only to ascertain the number, situations and periodic motions of the heavenly bodies, but the *physical cause of their mutual action upon each other*, which he terms *living astronomy*, to distinguish it from that which is vulgar and empirical.

It was also maintained by Newton, that all the phenomena of nature are resolvable into attraction and repulsion, which he referred to the agency of an all-pervading *ethereal substance, capable of contraction and dilatation.* But, as it is now demonstrable, that *caloric alone* is the cause of expansion and the elastic force of gases, vapours and volatile liquids, there can no longer be the shadow of a doubt that it is identical with the ether of Newton, the pneumatical power of Bacon and the universal igneous principle of the ancient Greek philosophers. Nor is it possible to deny that Newton has represented this principle as the proximate cause of cohesion, capillary attraction, chemical affinity and of universal gravitation; all of which he viewed as modified effects of one and the same agent. But owing to the vague and imperfect account which he gave of it, philosophers have even doubted the reality of its existence, and treated it as a chimera of the author's imagination, invented for the purpose of sustaining his theory of nature. The consequence of which has been, that the law of gravitation has been regarded as a comprehensive generalization of phenomena, for which no definite reason can be assigned; while the great and noble science of

chemistry, which, in a practical point of view, is far more important than astronomy, consists of an immense collection of facts and experiments, the connection of which with the phenomena of heat, light, electricity, cohesion, capillary attraction and gravitation, has never been distinctly understood, nor reduced to fundamental laws.

Had Newton discovered the simple law by which the ether produces the opposite effects of contraction and expansion, he would probably have traced its agency in the phenomena of combustion, solution, vaporization and all the molecular changes of matter. Or, had Dr. Black and his successors fully comprehended that universal law of caloric by which it attracts ponderable matter with a force that augments in proportion as bodies are deprived of it, they would have found that it is as capable, under such circumstances, of becoming a powerful bond of cohesion, as it is, under other circumstances, of dissolving their union, and of converting them into elastic fluids. But they have all overlooked the force of attraction, by which this subtile fluid is concentrated around the particles of rude matter, and thus rendered latent; and by which its self-repulsive force is counteracted.

Not being able to comprehend how one and the same agent could produce both attraction and repulsion, Buffon maintained that the powers of nature, which are known to us, may be reduced to two: *that which causes weight, and that which causes heat;* that to the power of attraction, joined to the cause of heat, may be referred all the phenomena of living and dead matter. Still the cause of attraction remained unex-

plained. Had Buffon advanced but one step farther, he would have resolved all the forces of nature into one and the same cause.

Since the discovery of latent heat by Dr. Black, philosophers have viewed it as the antagonist of that universal force by which all things are held together. When treating of liquids, Dr. Dalton observes, that they must be considered as bodies under the control of two most powerful agents, *attraction and repulsion*, the last of which he refers to caloric. Sir H. Davy also observes, that heat, or the power of repulsion, may be considered as the antagonist of cohesion; the one tending to separate, and the other to unite the particles of bodies. (*Chemical Philosophy*, page 30.) Still the important question recurs, what is the cause of attraction? Newton says, it is an *effect* of some unknown ethereal agent, and that it is the business of philosophy to find it out.

What, then, is the internal constitution of matter? Are the pores of bodies void of all substance? or are they pervaded by subtile and active matter? If so, what is it, and what are the laws by which it operates? It is quite certain, that until these important queries are resolved, the science of nature can never be established on the solid basis of fixed principles, but must remain, as heretofore, imperfect and vacillating.*

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* It was supposed by Epicurus and his followers, that "the atoms of fluids were smooth and spherical, by which they were enabled to glide freely over each other; but that the atoms of solids were hooked," as if their forms could change on passing from the liquid to the solid state. He also maintained that the

It requires no extended series of argument to prove, that *whatever the cause may be which moves atoms, must also be the cause which moves the largest bodies, for the simple and obvious reason that they are made up of atoms.* If it be true, that cohesion, capillary attraction and chemical affinity, be only modifications of gravity, as maintained by Newton, Laplace, Buffon, Morveau and other philosophers, it follows, that the whole theory of nature, whether mechanical, chemical or physiological, is resolvable into that of atoms, and the cause by which they are attracted and repelled, united and separated. If we are capable of discovering the cause which holds together the particles of a pebble, or crystal of ice, we are also capable of comprehending the cause which binds all things together by gravity. Newton expressly affirms, that "the drops of fluids affect a round form by the mutual attraction of their parts, as the earth affects a round form by the mutual attraction of its parts by gravity." (*Opticks*, book iii. page 370.)

It is self-evident, that if the particles of bodies be not endowed with inherent powers of motion, they

pores of bodies were void of all matter. (*De Naturâ Rerum*, book ii.) Others have supposed that the particles of bodies are glued together by an immaterial cement, as bricks are held together by mortar. (*Baxter on the Immateriality of the Soul.*) The Rev. W. Jones referred cohesion to the pressure of a *cold ether*, from the fact that liquids are converted into solids by cold. Ampère, Berzelius and some other modern philosophers have maintained that the atoms of bodies are endowed with electric polarity, or that their opposite sides are in different states of electricity; while the great body of chemists regard the whole subject as involved in profound obscurity.

must be impelled by some other agent; that is, they must act upon each other at a distance, without the agency of any physical tie, or by some intervening medium. Thus it will be found, that the primary object of science is to ascertain the cause which moves atoms, and the mode in which it produces so many and diversified effects; that chemistry and natural philosophy are only different branches of one great science, which cannot be studied separately from each other, without departing from the unity and simplicity of nature, all the operations of which are governed by the same code of physical laws, from the aggregation of crystals to that of suns, planets and their satellites.

I have shown, in the foregoing chapters, that the atoms of all bodies are surrounded with subtile and active matter, without which they could neither approximate nor recede from each other; consequently, would be passive and motionless; that the various forces, movements and changes of form which bodies undergo, are determined by the relative proportions of ethereal and ponderable matter of which they are composed; that when the *active principle* predominates, they are decomposed, or expanded into gases, vapours, or even flame, which is luminous ether; but that when the ratio of ponderable matter predominates, the attraction of caloric for the latter counteracts its self-repulsive force; by which gases are chemically united into vapours, with contraction of volume and diminution of elasticity, or condensed into liquids and solids.

Perhaps the most fruitful source of error in physics has been partial and limited views of nature; and the confounding of phenomena or effects with the cause

which produces them. Some modern writers on natural philosophy speak of *gravitation* as though it were "the animating principle of nature." In the fifth volume of the *Cabinet Cyclopedia*, we are told that, "all the great changes and revolutions of the bodies which compose our system can be traced to, or derived from, this principle." And Professor Bonnycastle observes: "The single principle of gravitation pervades the whole universe, and puts every spring and wheel in motion." * * * "From this active, invisible and invigorating *agent*, proceeds all that order, harmony, beauty and variety, which so eminently distinguish the works of creation." (*Astronomy*, p. 184, 8th ed.) But if gravitation were a universal principle of action in nature, it ought to explain the phenomena of solution, repulsion, evaporation, the expansive force of gases and fulminating compounds; in short, it ought to account for all the operations of chemistry, geology and meteorology; which is not the fact. It therefore follows, that there must be a principle of action in nature ulterior to that of gravitation, as admitted by Newton.

It might as well be said that *repulsion* is the animating principle of nature, as the general *attraction* termed gravitation. The true state of the case is, that both attraction and repulsion are subordinate, though universal effects of an all-pervading principle that surrounds every particle of matter in the universe; to which may be referred the phenomena of heat, electricity, light, evaporation and combustion, together with all the diversified transformations of matter.

It was by confounding the external world with the

impressions which it produces on the senses, that Berkeley was led to resolve the universe of matter into mind or spirit. What can we make of the monads of Leibnitz,—without parts, extension, figure or divisibility,—the essential properties of which are, nevertheless, perception and appetite? The mathematical theory of Boscovich, before noticed, is equally beyond the power of human comprehension. In the same spirit of metaphysical subtlety, the celebrated Kant denied the existence of ultimate atoms, by assuming that they were without extension or solidity; while he resolved heat, light, electricity and magnetism into the *power of attraction and repulsion*, as if such powers could exist without substance. Not less obscure is the modern doctrine which resolves light, heat and electricity into vibrations of some unknown hypothetical ether. Who can grapple with such shadowy and unsubstantial data?

It is an exceedingly partial and superficial view of caloric to regard it merely as the cause of temperature, fluidity, vaporization, decomposition, &c.; for it is self-evident that if the attraction of caloric for metals, ice and other bodies augments in proportion as they are deprived of it, it must be an attractive as well as a repulsive agent—an ethereal bond of cohesion, the force of which varies according to the relative proportions of caloric and ponderable matter. Every alteration in these proportions produces a change in the mechanical, chemical, and even vital properties of bodies.

That the force with which caloric combines with, and is concentrated around the particles of ponderable matter,

augments in proportion as they are deprived of it, may be regarded as a fundamental axiom, derived from the general experience of mankind; and it is founded on a law of nature which connects all the phenomena of molecular attractions with the theory of latent caloric. Without the recognition of this important truth, it is impossible to comprehend the most familiar phenomena of every-day life—why, for example, the atmosphere abstracts from animal bodies their vital heat, with a rapidity proportional to the reduction of its temperature; or why caloric is rendered a latent constituent of all matter. The attraction of ice for caloric exceeds that of water, because it contains less of it than water; the consequence of which is, that the particles of water are drawn closer together, and maintained in the solid form with a corresponding force of cohesion. If it be objected that water expands during congelation, it may be answered that its particles are arranged in series, forming angles of 60° and 120°, making large pores or cavities. Were it not for this, the volume of ice and other crystalline bodies would diminish on assuming the solid form. That the volume of ice is actually reduced, and its cohesion greatly augmented by the abstraction of caloric, is evident from the large fissures found in bodies of ice after an excessive frost, and from the rocky firmness which it exhibits.* Were it possible to reduce the temperature of ice 1000°, the attraction of caloric for it would be

* In fact, M. Brunner has recently proved by experiment, that when the temperature of ice is reduced from 32° F. to 4° F., its specific gravity is considerably augmented. (*Silliman's Journal*, Jan. 1846, p. 117.)

immense; while there would be a corresponding augmentation of its density and cohesion.

If the atoms of gold, silver, copper, iron, lead, tin and other metals, be surrounded with caloric alone, and if it have a definite degree of attraction for each, it must hold them together with a corresponding force of cohesion. Or if the atoms of oxygen, hydrogen and carbon, of vegetable matter, be surrounded with caloric, and nothing else, it must be the cause of their contraction and expansion, of their chemical union and decomposition, unless the atoms be endowed with inherent powers of attraction and repulsion; which is hypothetical and contrary to all analogy.

Should it be maintained, that electricity is a constituent of all bodies, I answer, that electricity, as it exists in a state of combination with the particles of ponderable matter is identical with latent caloric. For the proofs of this identity, the reader is referred to the next book, where it will be demonstrated that solar caloric is the basis of lightning; and that under all circumstances, however various the phenomena of electricity, they are only modified effects of the same agent which produces evaporation and solution.

The general recognition of this important truth will banish from the science of nature an immense mass of hypothetical speculation, and much of that complexity which has hitherto baffled every attempt to explain, in a satisfactory manner, the connection of heat and electricity with cohesion and chemical affinity. The absurdity of supposing that the atoms of bodies are surrounded with two distinct ethereal agents, one of which draws them together, while the other repels

them asunder, is too obvious to require a serious refutation.

By the attraction of caloric for ponderable matter, it unites and holds together all things; by its self-repulsive agency, it separates and expands all things.

To whatever portion of nature's wide domain we turn our attention, we recognize the operation of this universal law. Hence it is, to use the significant language of Bacon, that "heat and cold are nature's two hands;" which is a general though vague enunciation of the above law: for it is certain, that in a philosophical sense, the words heat and cold are only relative terms, which indicate different proportions of the same ethereal agent.

It is because the attraction of caloric for solids exceeds that of liquids, that their cohesion is greater than that of liquids. It is because the attraction of caloric for mercury is greater than for water, that the particles of the former are held together with a greater force of cohesion. When reduced to the temperature of —39°, this cohesion is so far augmented that it assumes the solid form, and acquires the power of attracting other bodies, the temperature of which is higher. When the hand is applied to frozen mercury, it is also held with great force, as iron is attracted by a powerful magnet when charged by a voltaic battery. It is therefore highly probable, that if the temperature of mercury were reduced —100°, it would abstract from animal bodies their vital heat with a force and rapidity resembling an electric shock; and that if it were possible to reduce its temperature a thousand degrees below zero, the attraction of caloric for it would

surpass all means of computation; while its cohesion and density would be proportionally augmented.*

It is owing to the attraction of caloric for gravitating matter, that when the hand is applied to iron, copper, gold, silver and other dense metals at very low temperatures, it adheres fast, and cannot be disengaged without lacerating the skin; or that when a portion of melted zinc is poured upon a solid plate of the same metal, there is a rush of caloric from the liquid to the solid, by which their particles are forced together; that when water is poured upon a block of ice 15° or 20° below zero, it is immediately converted into the solid state, and incorporated with the ice by virtue of the same force which causes universal attraction.

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* It is because caloric has a stronger attraction for iron, copper, gold, silver, platinum and other dense metals, than for silks, furs, down, woollens, resins, bitumens, sulphur, coal, iodine, bromine, dry wood, potassium, sodium, with innumerable other light bodies, that they abstract it more rapidly from warm-blooded animals, and consequently feel colder to the touch. It is because caloric has a powerful attraction for the dense metals, that it is concentrated and held around their particles with immense force, and cannot be disengaged from them, even in small proportions, without the application of great mechanical pressure. Accordingly, we find that they are good conductors of caloric, and cohere together with a corresponding force of aggregation. Their cohesion and conducting power are also augmented in proportion to their condensation by pressure, as in wire drawing; from which it follows, *cæteris paribus*, that their affinity for caloric, on which their cohesion and conducting power depend, increases with their density and loss of caloric. It is equally true of all other bodies, without a single exception, that their cohesion and conducting power are determined by the relative degrees of their attraction for caloric, which augments in proportion as they are deprived of it.

It is by the attraction of caloric for ponderable matter that it combines with different bodies and produces their liquidity; it is also by virtue of the same attraction, that liquids are enabled to dissolve and combine with other bodies. Philosophers have generally assumed, that cohesion is the antagonist of chemical affinity, and that they are produced by different causes. But the most obvious phenomena of nature demonstrate that they are produced by one and the same cause, and that all molecular combinations result from the attraction of caloric for other matter. The only difference between cohesion and chemical attraction is, that the one is exerted between homogeneous atoms, and the other between heterogeneous atoms, which vary in size, and in the degrees of their affinity for caloric. It is owing to the attraction of caloric for ponderable matter, that when a piece of tin is laid on a portion of melted lead, the tin is dissolved, and its particles intimately blended with those of the lead. In all such cases, it is undeniable that the atoms of the liquid are forced to combine with those of the solid, by the agency of caloric alone; for the obvious reason, that no other agent has been employed to produce the effect.

It is in this way that all metallic alloys are formed. If six drachms of solid zinc be brought in contact with an ounce of melted copper, there is a transition of caloric from the one to the other, by which the particles of zinc are transported from their original place, and intimately combined with those of the copper, by the same power which unites the atoms of individual metals. The fact is, that all the elements of nature

may be united by fusing them together, and again separated by larger proportions of the same agent. If a mass of granite or basalt were plunged into a cauldron of burning lava, they would be intimately incorporated throughout by the transition of caloric from the lava to the solid rock. It is scarcely necessary to add, that the various materials of which all volcanic rocks are formed, are thus united and held together, by the same cause which maintains the solidity and cohesion of the earth.

The art of plating bars of iron, copper, &c., with gold, silver, zinc, tin and other metals, is founded wholly on the cementing power of caloric, which forces them together, by what may be termed chemical cohesion, to distinguish it from the aggregation of simple bodies. Plates of gold are made to unite with bars of iron and other metals, by being pressed together and placed in a stove or furnace.

When bars or plates of iron are thoroughly cleaned and polished until quite bright, and immersed in melted tin, they are soon covered over with a thin white coat; or if a slip of copper be perfectly cleaned and polished, then heated, and rubbed over with a piece of tin, a portion of the latter metal combines with the copper, giving it a silvery coat, which adheres to it for the same reason that the hand adheres to frozen mercury, or other metals, when reduced to very low temperatures.

The common mode of tinning copper vessels, is to make the surface bright by scraping and washing them with a solution of hydrochlorate of ammonia. They are then warmed, when the tin is melted and poured

into them, by which it incorporates with every part of their surfaces, and when cold remains firmly united. In the same way, iron vessels are coated with zinc. It is well known that silex cannot be made to combine with potassa or soda to form glass without the agency of heat, which is equally essential to the welding of iron and to the soldering of other metals. The adhesive property of wax, gum, sugar, &c., when in a state of fusion by caloric, is equally familiar to every one.

The truth is, that all the internal and external properties of bodies, whether mechanical or chemical, such as hardness and softness, density and lightness, tenacity and firmness, volatility and combustibility, are determined by their relations to caloric.

It is well known to spinners and weavers, that the fibres of cotton, wool, flos-silk and flax, are brittle during cold weather, and that if their rooms are not kept at a proper temperature, their threads often break. On the other hand, some of the most brittle substances in nature, such as glass, may be spun into thread almost as fine as that of the silk-worm, when in a state of fusion by heat; while butter, lard and many other substances that are soft and tenacious when warm, become hard and brittle at very low temperatures. The same is true of iron and some other metals, which become brittle like glass or ice during excessively cold weather. The rationale of this will appear from the general fact already established, that the attraction of caloric for bodies augments in proportion as they are deprived of it; the consequence of which is, that it is more concentrated around their

particles, which cohere with a corresponding force, producing great hardness; but when by a blow, or any sudden force, they are removed in the slightest degree from their place, the cohesion is broken, and they fly asunder. In the state of liquids, their particles glide freely over each other, without losing their hold, as one magnet glides over another. This is the case with all the malleable metals, and with the tenacious oils, gums, glue, &c. until reduced to very low temperatures, when they all become more or less brittle like ice. It is owing to the augmented cohesion and hardness of very cold iron that it will not bend, but snaps asunder, —that is, its particles refuse to glide over each other; while, at higher temperatures, the greater extent of the igneous atmospheres that surround them holds on to them at greater distances, though with less force, causing toughness or tenacity.

When two pieces of lead, tin, zinc or any other soft metal, are pressed together with sufficient firmness, their atoms are brought within the range of this attractive medium. The same is true of the hardest substances, when softened by heat. Even polished plates of glass, marble, wood and many other bodies, when brought into close apposition, cohere, but still better when fused together by heat.

It was before stated that the ethers, alcohol and many other liquids, have no cohesion whatever at ordinary temperatures; and when released from the pressure of the atmosphere, are expanded into vapours by the repulsive power of their latent caloric. They are accordingly very bad conductors, like silks, woollens, furs and other light bodies, that are full of ca-

loric. Yet by a sufficient reduction of temperature, their attraction for the igneous principle is so far augmented, that their particles are drawn closer toward each other, and bound together in the solid form; and if their temperature could be reduced 1000° F. there is every reason to believe that their cohesion would equal that of salts, rocks, or even the denser metals.

From all the foregoing facts and arguments it is evident, that attraction and repulsion, hardness and softness, solidity and liquidity, density and lightness, are not essential conditions of bodies, but depend on the relative proportions of ethereal and ponderable matter of which they are composed; that the most elastic gas may be reduced to the liquid form by the abstraction of caloric, and again converted into a firm solid, the particles of which would cling together with a force proportional to their augmented affinity for caloric. On the other hand, it is equally evident, that by adding a sufficient quantity of the same principle to the densest metals, their attraction for it is diminished, when they are expanded into the gaseous state, and their cohesion destroyed.

Having met with a few individuals who cannot readily conceive how a self-repulsive agent can operate as a bond of cohesion between the particles of common matter, it may be proper to show, by a few familiar examples, that the force with which liquids hold together the particles of solid bodies, is not in proportion to the attraction of their own particles for each other, but in proportion to their affinity for the solids.

It is well known that at ordinary temperatures of the atmosphere, the particles of water cohere with very

slight force, if not deprived of air. It is also known, that when granite, lime, clay and marble, together with all other rocky and earthy bodies, are reduced to the condition of a perfectly dry and impalpable powder, their particles glide freely over one another, having little or no attraction for each other. On adding to this powder a due proportion of water, they are found to unite together by a very strong attraction, forming dense and highly tenacious mortar. The less water such ingredients contain, the stronger is their attraction for it. Hence it is, that the cohesion of mortar augments in proportion as it is deprived of water by drying; or that when the earth has been parched by a long drought, it attracts and absorbs more rapidly a shower of rain, than when in a moist state, in the same way that all bodies absorb caloric with a force and rapidity in proportion as they are deprived of it. In like manner, the cohesion of mortar is diminished by adding to it larger proportions of water, in the same manner that the cohesion of ice, metals and other bodies, is lessened by increasing their temperatures; that is, by altering the relative proportions of caloric and ponderable matter.

Innumerable liquids might be mentioned, the atoms of which have no cohesion among themselves, which, nevertheless, operate as a bond of union among the particles of various other solids when in the state of powder. It is by virtue of the affinity between wheat flour and water, that they form a cohesive dough; and so of a thousand other bodies, the particles of which have little attraction for each other, without the medium of a liquid; but if caloric be indispensable

12

to fluidity, it must be the ultimate and efficient cause of attraction between liquids and solids. It is the caloric of melted wax, glue, paste, gum, molasses, &c., by which they are enabled to combine with and hold together the particles of solid bodies, for the same reason that the caloric of melted metals, rocks, &c. enables them to combine with solids, and to hold them together. If sulphate of lime be reduced to the state of powder, its particles have scarcely any cohesion for each other; but if converted into mortar by the admixture of water, they cohere into a rocky cement, the firmness of which is in proportion to the force of attraction between the water and the lime.

In fine, the more profoundly we scrutinize the operations of nature, the more evident it becomes, that all the modifications of force by which the particles of bodies are united, depend on the agency of a self-repulsive ether. It is therefore ridiculous to maintain, that an agent which repels its own particles, cannot hold together the particles of other bodies.

THEORY OF CONDUCTION AND RADIATION.

The most general and well-established fact connected with conduction is, that all the lightest bodies in nature are bad conductors of caloric and electricity; such as furs, eider down, silks, woollens, cottons, resins, lac, bitumens, phosphorus, dry wood, &c. among solids; and ether, alcohol, oils and water among liquids; while gases are still worse conductors; whereas, the densest known bodies are good conductors, such as gold, silver, copper, iron, zinc, tin, lead, &c. Next to the pure

metals in conducting power, are rocks, gems, flint-glass, porcelain and the denser liquids, as solutions of the acids and alkalies. Owing to their extreme fusibility, it is difficult to determine the conducting power of potassium and sodium; but it is certain that they are bad conductors of caloric, and probably worse than water, in proportion to the difference between their specific gravities.

It has also been proved in the preceding chapter, that all the lightest known bodies are composed of large proportions of caloric, (which repels its own particles,) compared with the quantity of ponderable matter.

The atoms of gases being surrounded by extensive atmospheres of caloric, are therefore bad conductors. It was found by Sir Humphrey Davy, that when metals, such as mercury, tin and arsenic, are converted into the gaseous state, they become, like other gases, non-conductors of electricity. (*Works*, vol. ii. p. 22.) The same thing is true, though in a less degree, of all the lighter liquids and solids.

On the other hand, the atoms of the metals which contain less caloric around them in proportion to their size, and being closer together, attract and conduct it from one to the other, with different degrees of rapidity; modified by the arrangement of their atoms, and perhaps by other circumstances not yet fully understood. It is, doubtless, owing to the crystalline structure of ice, that it is a worse conductor of electricity than water. May it not be owing to the same cause that glass, resins, sulphur and some other bodies are better conductors of electricity in the liquid than in the solid state?

That the conducting power of all bodies augments in proportion as they are deprived of caloric, other things being equal, may be regarded as absolutely certain.

The conducting power of metals is increased in proportion to their condensation by pressure, for the same reason that it is augmented by a reduction of temperature,—that is, owing to the loss of a portion of their heat. Caloric has a stronger attraction for pure metals than for their oxides, chlorides, fluorides, bromides and iodides; their specific gravity, cohesion and conducting power are also greater.*

The connection of this subject with the philosophy of radiation is exceedingly important, and seems never to have been rightly understood. It was ascertained by a great variety of experiments performed by Dr. Wells, with a view of explaining the production of

* Lord Bacon observes, in the Second Book of the *Novum Organum*, that it should be inquired why metals and stones feel colder to the living body than the fur of animals, silks, woollens, feathers, wood, &c.; whether the latter contain more inherent heat than the former; and if so, whether it be owing to their oily nature, or to the air which they contain. Dr. Thomson thinks that it is owing to the *air within their pores;* while the great mass of writers on Chemistry and Physics, resolve the whole mystery by telling us, that they *are bad conductors of caloric,* which is the very thing to be explained. The hypothesis of Dr. Thomson is so far from affording a solution of the difficulty, that he does not explain why air is a bad conductor. The simple matter of fact is, that all those articles of clothing which retain the caloric of the body most effectually, contain a large amount of the igneous principle, and are therefore bad conductors. For the same reason, they are highly combustible; and, when submitted to friction, afford abundance of the electric ether; on which account, they have been called electrics.

dew. He found that eider down, wool, cotton, grass, the leaves of trees and all vegetable substances, parted with their caloric more rapidly by radiation, than rocks and metals; that while dew collected in large quantities on the former, during clear nights, there was generally little or none on the latter. But no one seems to have suspected, that the radiating power of bodies was determined by their latent caloric, or that it was even modified by their attraction for it.

It was supposed by Prevost, whose opinion has been adopted by a majority of writers on Chemistry and Natural Philosophy, that the tendency of all bodies to an equilibrium of temperature, is owing to a perpetual exchange of caloric from one to the other by radiation. But it is evident from the foregoing facts, that the motions of caloric by which it passes out of one body into another, are owing to its attraction for ponderable matter, as well as to its self-repulsive or radiating power. When a hot body is placed *in vacuo*, and at a distance from other bodies, it parts with caloric by radiation alone, with a rapidity proportional to temperature. When placed in atmospheric air, it loses the same quantity of caloric by radiation, while an additional portion is abstracted by the contiguous particles of air.

It is generally stated, that bodies cool about twice as fast in air as *in vacuo*. Count Rumford found that a thermometer cooled from 212° F. to 32°, *in vacuo*,

in	10 m.	5 sec.
in air	7	3
water	1	5
mercury	0	36

But if it be true that all bodies attract and absorb caloric with a force and rapidity in proportion as they are deprived of it, it is obvious that in air, —50°, the thermometer would sink much more rapidly. It is equally obvious, that when placed in water, mercury and other dense liquids, the effect is produced wholly by the attraction of caloric for them, and without radiation.

It was before stated, that caloric has but little attraction for the metallic oxides, compared with the pure metals; and that their cohesion, specific gravity and conducting power are accordingly small. The experiments of Leslie prove that their radiating power is much greater. He found that while the radiating power of clean lead was only 19, it rose to 45 when tarnished by oxidation; that the radiating power of plumbago was 75, and that of red lead 80. He also discovered, that while the radiating power of gold, silver, copper and polished tin was only 12, that of crown-glass was 90, sealing-wax 95, resin 96, writing-paper 98, and lamp-black 100.

In short, all light bodies, which are full of latent fire, and therefore bad conductors, are proportionally good radiators; while the denser metals, which contain less of it, hold on to it for a longer time, under the same circumstances. But as their affinity for caloric diminishes in proportion as they acquire more of it, they also radiate freely at very high temperatures. On the other hand, if the dense metals could be reduced 1000° below zero, they would attract and conduct it with a force and velocity like lightning.

The more careful and reliable experiments of Dr.

A. D. Bache and of J. Brocklisby, have proved that colour alone exerts no influence upon the radiating power of a surface.

It has been long known that metallic vessels, such as tea-urns, retain their temperature much longer than vessels of stone, earthenware, wood, &c., which have less affinity for caloric than metals; and that the same metallic vessels retain their temperature longer when highly polished than when rough. The latter effect would seem to be owing to the closer proximity of the particles composing a smoother surface; for it has been found, that when wood is reduced to sawdust, it radiates more rapidly than in the solid state; that locks of wool, cotton, flos-silk, &c., radiate better than the same materials when spun and woven, by which their fibres are brought closer together. So when the particles of a metallic surface are brought near to each other, they have a stronger affinity for caloric than when more distant, and thus prevent it from flying off, for the same reason that the cohesion and conducting power of metals are augmented by condensation, as in wire drawing. Melloni found that the radiating power of metals was impaired by polishing their outer layers, which are thus condensed by the pressure used, and that cast silver radiates one-third more than hammered silver, which is more dense; the polish of surface being the same. Is it not owing to the same cause, that electricity escapes more rapidly from rough surfaces which consist of innumerable points, than from such as are smooth and highly polished?

Connected with this subject is another fact, that

has never been explained, and which may appear at variance with the above theory of radiation, until duly considered. It has been ascertained by Leslie and other experimenters, that *the reflecting power of bodies is inversely as their radiating power; and that their power of absorbing caloric is proportional to their radiating power.*

It was discovered by Newton, that the surfaces of glass and polished marble are covered over by an invisible and repulsive medium, which prevents their actual contact, even when pressed together with great force. It is doubtless owing to this elastic and repulsive ether, which adheres to polished metals by a still stronger attraction, that when water is poured upon them, it glides over, without wetting or touching them; and that steel needles are enabled to float on the surface of water, notwithstanding their greater specific gravity. It is this thermo-electric ether which prevents polished metals from absorbing caloric, and causes it to rebound from their surfaces by reflection; while light bodies, and metals that are rough or uneven, which contain less of the repulsive medium over their surfaces, absorb more and reflect less caloric.

CHAPTER II.

CHEMICAL ATTRACTION.

"Of the great and comprehensive laws, which rule over the widest provinces of natural phenomena, few have yet been disclosed to us."—WHEWELL.

WHETHER in a practical or philosophical point of view, a perfect theory of chemistry would be of far higher importance than that of universal gravitation; for it would lead to a knowledge of all the properties of the elements by which we are surrounded, and of their application to the extension of human happiness. Yet there never was a period in the history of science, when greater uncertainty prevailed in regard to the primary cause of chemical action, than at the present time. The celebrated Œrstedt regards the science of chemistry as in the same condition now, that mechanical philosophy was in the age of Galileo, Descartes, Huygens and Newton; and he maintains that no general principle has been discovered which governs all affinities. (*Sur l'Identité des Forces Chimiques et Électriques.*)

Notwithstanding the recent progress of atomic chemistry, Dr. Prout observes, that this great science "is founded solely on experience, for the phenomena of which we can assign no reason." (*Bridgewater Treatise,*

p. 29.) On the same subject, the language of Professor Whewell is still more emphatic and precise. In the concluding chapter of his *Treatise on Astronomy*, he states, that "*no one has pointed out any common feature between chemical affinity and the attractions of which we know the exact effects; and that we are still more profoundly ignorant of the vital principle.*" Lord Brougham also observes, in his *Natural Theology*, that "we know little or nothing of the minute motions by which the particles of matter are arranged, when bodies act chemically on each other." (Vol. i. p. 373.) Lastly, Liebig says: "the ultimate causes of combinations and decompositions are chemical forces, and these differ from all other forces, inasmuch as we perceive their existence only by their manifestations when bodies come into immediate contact with each other." (*Letters on Chemistry*, p. 32.) Alas! if this be a true representation of the actual state of human knowledge, is it not high time that men should awake from their lethargy, and observe more attentively all the circumstances connected with chemical action? It was profoundly observed by Bacon, that "*in all generation and transformation of bodies, we should inquire what is added, what remains and what is lost,—what is united and what is separated,—what hinders, what commands and what gives the motion.*" (*Novum Organum.*)

This is the true character of the inductive philosophy; careful observation, rigid analysis, the rejection of all hypotheses and the undue authority of distinguished names, must ultimately lead to the solution of all physical mysteries. It is doubtless an object of great practical importance to know the proportions in

which the elements of ponderable matter unite to form water, alcohol, ether, acids, alkalies, salts, rocks, &c.; but it is still more important to know what the agent is, by which they are brought together and maintained in a state of intimate combination.

That the ancients regarded fire as the great agent in all the transformations of nature, would appear from the etymology of the word chemistry, which, like the Greek *χημεια*, *Chemeia*, was derived from the Oriental ביכה, *Chime*, signifying Heat, according to the learned Parkhurst. But Sir William Drummond quotes a passage from Zosimus, of Panopolis in Egypt, who states, on the authority of the Hermoic books, that the art *Chemeia* took its name from the word *Chema*. (*Origines*, vol. ii. p. 264.) Now it is remarkable, that this word was employed, with slight dialectical variations, by several of the most ancient Oriental nations, to represent Heat. By the Egyptians it was called חם, *Khem*, or *Ham* with the aspirate. By the Chaldeans and Hebrews it was called חכה, *Kheme*, or *chema*, signifying the solar Fire, which the Arabians called *hama*. In fact, the word *hama*, Heat, has been traced in the old Pahlivi language, which has been regarded by competent authorities as the mother of the Sanskrit, the Zeud of Persia, the ancient Kouwen of China, and some other Asiatic tongues. Nor is it unworthy of notice, that the name of *Brahma* was derived from the Sanskrit *bra*, to create, and *hma*, or *homa*; signifying the creative Fire.

The proximate agency of caloric in chemical affinity might have been long since recognized, but for the difficulty of comprehending how a self-repulsive agent

could become a cause of attraction. But it is self-evident, that if a globule of ice be composed of oxygen, hydrogen and caloric; and if there be an attraction between the particles of ice and caloric, they must be held together with a force equal to that attraction; and so of all other bodies. Besides, if it were demonstrated, that some other ethereal agent, such as electricity, surrounds the particles of ice, it must have an attraction for them like caloric, or it could not become a bond of union. It therefore follows, that in either case, the effect results from one and the same fundamental law, which involves an identity, or unity of causation. In addition to what was before stated, *page* 177, the following facts will further illustrate the manner in which a self-repulsive agent becomes a bond of union between the particles of inert matter, which have no inherent affinity for each other.

It is well known, that the particles of ether, alcohol and many other volatile liquids, repel each other with such force, that when the pressure of the atmosphere is removed, they fly asunder, and assume the form of elastic vapours, thus presenting the character of an idio-repulsive agent. It is also known that when the particles of resin, charcoal and hundreds of other bodies, are reduced to the state of an impalpable powder, like the dust of our roads after a long drought, they have little or no attraction for each other; but that if they be brought into contact with the above volatile liquids, they cohere with considerable force. Why? Undoubtedly because there is a mutual attraction between the liquids and powders, which coun-

teracts the repulsive force of the liquids, and prevents them from flying off in the form of vapour.

It has been long known that platinum when reduced to the form of a black powder, absorbs about 800 times its volume of oxygen gas, which is thus condensed around its molecules. During this process, the caloric which maintains the oxygen in the gaseous state must be given out, yet so gradually that no sensible elevation of temperature is observed. When a jet of hydrogen gas is thrown upon the powdered platinum, it combines with the oxygen condensed in the interior of the mass, by which water is generated, and heat evolved, until the hydrogen is inflamed, and the platinum made red hot. If the jet of hydrogen be interrupted, the pores of the platinum become immediately filled again with oxygen; showing that this absorption of gases by porous solids is greatly augmented by caloric. We are further authorized to conclude, that the latent caloric of oxygen is the cause of its primary combination with, and condensation around, the molecules of platinum: for when raised to the temperature of 572° F.; powdered glass possesses the same property of absorbing and condensing oxygen as spongy platinum at ordinary temperatures of the atmosphere. In fact, there is a large class of metals, which, when reduced to a state of minute division, combine rapidly with oxygen at ordinary temperatures: such as iron, nickel, cobalt, uranium, lead, &c. When iron is in mass, it has but little tendency to oxidation: but when firmly pulverized, it cannot be brought in contact with atmospheric air

without becoming red hot, and converted into an oxide.

If the particles of dust had no cohesion for each other whatever, they would represent the condition of ultimate atoms wholly deprived of caloric, which could neither approximate nor recede from each other. At the temperature of 67° F. water is an elastic fluid *in vacuo;* but if a thin film of water be placed between two plates of glass in an exhausted receiver, they cohere together, because the water is more strongly attracted by the glass, than repelled by its own particles. However imperfect such illustrations may be, they are sufficient to prove that a self-repulsive agent may become a bond of attraction to other bodies. But the fact which must forever set this question at rest is, that the attraction of all bodies for caloric augments, *cæteris paribus*, in proportion as they are deprived of it, and that their cohesion augments in the same ratio.

To those philosophers who have regarded electricity as the proximate cause of molecular attraction, it may be somewhat surprising that I have proceeded so far without an examination of the facts on which the electro-chemical theory was founded.

To this I answer, that no general law of electric action has ever yet been pointed out capable of explaining all the phenomena of molecular forces; in short, that nearly all the leading facts, connected with the theory of electricity, are involved in the utmost obscurity and uncertainty.

I have shown that caloric is a universal and independent agent, which may be everywhere recognized

as a source of power and motion—of contraction and expansion—of solution and recombination; and that it is a principle of action in all the proceedings of nature.

But, in regard to electricity, we are not informed by those who assign it as the cause of chemical action, whether it be a material agent which may be added to, and subtracted from ponderable matter, or a mere effect resulting from the inherent properties of common matter. The electro-chemical theory of Sir Humphrey Davy was founded on the well-known fact, that when bodies are in different states of electricity, they attract each other. Starting from this point, he assumed, first, the existence of two electric fluids, each of which has an attraction for the other, and repulsion of its own particles; secondly, that all bodies which combine chemically, are in opposite states of electricity. Finding that the atoms of oxygen, chlorine, fluorine, iodine and bromine, were attracted by the positive pole of the voltaic battery, he inferred that they were combined with negative electricity; while all those bodies that were attracted to the negative extremity of the battery, were supposed to be electro-positive; and that in consequence of the attraction existing between such bodies, they rushed into a state of chemical combination, when the two electricities assumed the form of light, or fire. (*Phil. Transactions for* 1806.)

It would be an irksome task to detail all the objections that might be urged against this ingenious hypothesis. That it was not understood by Sir H. Davy himself, is manifest from the fact, that, in the same

Lecture, he asks the question, "May not the remote cause of electrical energy be identical with chemical affinity, and an essential property of matter?" He also observes, in his *Chemical Philosophy*, that "electricity seems to result from the general powers and agencies of matter." How is it possible to reconcile or comprehend such vague and contradictory views?

Had not this distinguished chemist attached himself in early life to the hypothesis, that "caloric was a mere effect," instead of being an all-pervading and sufficient cause of motion, his own experiments would have led him to perceive that caloric and electricity are mutually convertible into each other; for he was among the first to demonstrate that electricity is capable of producing the same effects which are usually ascribed to caloric. By means of a wire, connected with the poles of a battery, he caused water and other liquids to boil.

Let us examine briefly some of the consequences which flow from the hypothesis that caloric results from the combination of two electric fluids, admitting for the present, (what has never been established,) that electricity consists of two mutually attractive fluids.

The hypothesis assumes in the first place, that all the elements of ponderable matter are reducible to two classes, one of which is united with *positive*, and the other with *negative* electricity; the mutual attraction and combination of which produce the phenomena of heat, and the chemical union of bodies. But it is self-evident, that if heat result from the union of two electric fluids, all simple bodies must be without

caloric, until they unite chemically, which is contrary to matter of fact; for it has been proved in the preceding part of this work, that *all bodies are composed of caloric and ponderable matter;* a fact which cannot be predicated of electricity, unless we admit, that, in its latent or combined state, it is identical with the omnipresent igneous principle. It is impossible to imagine anything more at variance with common sense and the universal experience of mankind, than the supposition that caloric is the offspring of electricity; or that an universal agent should be the effect of any other power which is not universal.

Another objection to the electro-chemical theory arises from the fact, that bodies which are assumed to be in the same electric state, unite chemically.

For example, oxygen combines with chlorine, iodine and bromine, making chloric, iodic and bromic acids; while sulphur, phosphorus, carbon, hydrogen and the metals, which are considered to be in an opposite state of electricity from the above elements, combine chemically with each other as well as with oxygen, chlorine, &c. Besides, it is not true that oxygen, chlorine, iodine and bromine, are uniformly in the same electric state; for it is very well known that when chloric acid is decomposed, its elements are conveyed to different poles of the battery; that when sulphurous and sulphuric acids are decomposed by the pile, sulphur goes to the negative pole; but that when sulphuretted hydrogen is decomposed, sulphur goes to the opposite pole; that when carbon, selenium, arsenic and tellurium are united with oxygen, they are positive, but negative with hydrogen; proving that bodies are

neither essentially positive nor negative, and that they vary in this respect according to circumstances; consequently, that all classifications of bodies founded on their electric polarities are fallacious.

Dr. Thomson observes, that "if chemical affinity were merely the result of different states of electricity, bodies could not remain united unless these different electrical states were permanent. But if the positive and negative electricities combine and fly off in the form of fire, there must be an end of the different electrical states which caused them to unite, and of course the union must cease, which is contrary to matter of fact." (Thomson on *Heat and Electricity*, p. 335.)

A still more fatal objection to the electro-chemical theory is, that it affords no explanation whatever of cohesion or simple aggregation; whereas I have shown that the particles of homogeneous bodies are held together by the same cause which maintains the chemical union of heterogeneous elements; that the particles of copper are held together by the same agent that causes it to combine with zinc and other metals: but who has ever maintained that the atoms of homogeneous bodies are in different states of electricity?

It is not surprising that M. Becquerel, who follows Davy and Berzelius in referring chemical attraction to electricity, should have admitted that cohesion is a stumbling block (*la pierre d'achoppement*) in the way of every attempt hitherto made to connect the theory of chemistry with that of electricity. (*Traité d'Électricité et du Magnétisme*, tom. iii. p. 369.)

Those who regard caloric and electricity as distinct

agents, and the latter as the cause of chemical affinity, make caloric the cause of repulsion. Nothing could be more absurd than such partial and contradictory views of nature. Has it not been known, ever since electricity was first studied as a science, that it possesses the power of repulsion as well as caloric? I have also proved that the effects of caloric are not limited to its self-repulsive agency; that it has an universal attraction for ponderable matter, and repulsion of its own particles, by virtue of which it binds bodies together, or tears them asunder, according as it pervades them in greater or less proportions; and it will be shown hereafter, that all the motive powers of electricity, whether of high or low tension, are governed by the same fundamental law; that all the most powerful displays of electric action are only modified effects of that principle or essence which warms in the life-giving solar beams, and preserves the universe in a state of unceasing motion.

It is because philosophers have not sufficiently examined the relations of heat and electricity, and the law by which they are connected with ponderable matter, that almost every department of Physics has become involved in profound obscurity. It is self-evident, that if electricity be a bond of union between the particles of bodies, it must have an *attraction for them;* a circumstance which has been overlooked by Davy, Berzelius, Ampère and their followers. Dr. Thomson observes, that "with respect to the unknown link which unites electricity to atoms, and keeps it united with them, we are quite in the dark." (*Inorganic Chemistry*, vol. i. p. 40.)

Never can the science of chemistry be reduced to the simplicity of established principles, until men shall recognize the relations of caloric and electricity, and the universal law by which they are connected with ponderable matter.

When a bar of iron is charged with the electric ether, it attracts iron filings, which collect around it in large bunches, each particle clinging to the others, like bees suspended from the branch of a tree. But if electricity be a self-repulsive agent, it must have a still stronger attraction for the particles of iron, or it could not become a temporary bond of union between them; and that it is the true cause of magnetic attraction in soft iron, is obvious from the fact, that when it is withdrawn the attraction is destroyed.

At the same time, it is equally evident that electricity is not the generic principle of action in nature. If so, it ought to be everywhere present under all circumstances; but so far is this from being the fact, that in its most copious and concentrated form, (that of lightning,) its manifestations are only occasional and momentary. Besides, if electricity were the prime mover, it ought to be the cause of fluidity, evaporation, vapourization and those expansions of the atmosphere on which all its circulations depend. It is true that when sufficiently concentrated, it produces the same phenomena which are universally ascribed to caloric; that is, it raises the temperature of bodies, converts solids into liquids, vapours and gases; ignites combustibles, and produces the chemical union of bodies.

If then there be any truth in the great fundamental

axiom, that *the same effects must be referred to the same cause*, it is clear that electricity is only a modification of the omnipresent igneous principle. This identity is indicated by the fact, that when a current of the electric fluid is made to combine with metals, until they are melted or ignited, its properties are so far changed, that it no longer produces a shock, but in all respects exhibits the same phenomena which result from the heat of combustion. Dr. Hare attributes the explosive power of gunpowder and other fulminating mixtures to electricity, which is wholly unintelligible on the supposition that caloric and the electric fluid are distinct agents; for it is certain that the expansive force of all such compounds is owing to their sudden conversion into gases, and that gases are expanded by caloric as certainly as that the elastic force of steam is due to the same agent.

A thousand facts might be adduced to prove the radical identity of caloric and electricity. Those light and highly combustible bodies which afford the largest amount of caloric by friction, such as furs, silks, woollens, resins, sulphur, &c. also afford the largest proportions of electricity during the same process, and therefore have been termed electrics. Moreover, the strong acids, which give out the most heat during chemical action, afford the largest supply of electricity when acting on the metallic plates of a voltaic battery.

Again, those bodies for which caloric has the strongest attraction, such as metals, conduct it most freely. The same is true of electricity. Hence it is that both caloric and electricity disappear most rapidly when in the vicinity of good conductors, being at-

tracted by them and incorporated with their substance. It is thus that flashes of lightning are absorbed by the earth and rendered latent. Or, if a light feather be charged with electricity, and suspended in the still air of a room, at equal distances from sticks of resin, sulphur, glass and *metals*, it will approach the latter in preference to the former, *cæteris paribus*, with a force and rapidity that varies inversely as the squares of the distance.

If it be true that caloric and electricity be only modifications of the same agent, the electro-chemical theory becomes intelligible, and may be reconciled with the chemical agency of caloric. For example, those bodies which have the strongest tendency to unite chemically with each other, are said to be in opposite states of electricity. It is also certain, that the same bodies which contain different quantities of caloric, are most disposed to unite chemically; while those which have nearly the same relations to caloric have little attraction for each other, such as sulphur and phosphorus, potassium and sodium; the reason of which is, that a transition of caloric from one body to another is indispensable to all chemical combinations.

Every chemist knows, that he cannot carry on his distillations, separations and recombinations, without the agency of heat. But, regarding this as an incidental circumstance, he resorts to the agency of electricity for a solution of the problem, without inquiring into the source of this mysterious agent, or whether it could have any existence independent of the igneous principle.

The controlling agency of caloric in the phenomena

of chemistry, may be traced in all the decompositions and recombinations that are perpetually going on throughout nature. The truth of this proposition is attested by the vast amount of chemical action within the torrid zone, and within the temperate latitudes during summer; while in the regions of perpetual congelation there is no chemical transformation. It is well known, that animal and vegetable matter may be preserved without alteration for unlimited periods of time, in conservatories of ice or snow.* It is therefore obvious, that if the earth could be wholly deprived of solar caloric, all its chemical motions and changes would cease. It was admitted by Dr. Black, that "*heat is indispensable to chemical action, by overcoming the cohesion of bodies, and thus enabling them to exert their attractive powers.*" But I have proved that the agency of caloric is not confined to the mere separation of bodies; that the same agent which expands

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* Nothing could more clearly illustrate this fact, than the account of a huge elephant (or mammoth) discovered in the midst of a large mass of ice on the shore of the frozen ocean, near the mouth of the river Lena in Siberia; where it must have remained for thousands of years, as it belonged to an extinct species. When first discovered, in 1799, by a Tonguiese fisherman, the carcass was perfectly fresh and entire, parts of which were given by the neighbouring Jackouts to their dogs; while the remainder was devoured by wild beasts, after its disengagement from the ice, when its skin, bones and teeth were removed to Petersburg. Its neck was covered with a long mane, and the rest of its body with black hairs and a reddish fur or wool. The tusks were nine feet long, and weighed 350 pounds. For further particulars in regard to this curious discovery, see Cuvier's account, extracted from the *Memoirs of the Petersburg Academy*, and quoted by Bertrand in his *Revolutions of the Globe*.

them into vapours and gases, causes them to unite chemically with each other, to form new compounds, in obedience to the same law by which liquids are enabled to dissolve and unite chemically with solids; that is, by the attraction of caloric for ponderable matter.

The most extraordinary fact connected with the history of modern science is, that while *caloric* is constantly employed in all the operations of chemistry, and the arts of everyday use, several distinguished modern philosophers have refused it a separate numerical station among the elements; treating it as an incidental or subordinate effect of those powers and changes of which it is the primary and efficient cause.

When Count Rumford and Sir H. Davy supposed that heat was motion, they mistook the effect for the cause; for I have shown that all the contractions and expansions of bodies, whether solid, liquid or gaseous, result from their various relations to caloric. If a portion of alcohol or water be put into a Florence flask, their particles remain comparatively tranquil; but when placed over a burning lamp, a rapid intestine motion begins, and augments in proportion to the increase of temperature, until they are driven off in the form of steam. Nothing, however, could be more absurd, than to confound the motion of ebullition with its *cause*, which is evidently something derived from the lamp; for when the source of heat is removed, the ebullition and vapourization cease.

When Lavoisier pointed out the extensive agency of oxygen in combustion and fermentation, he overlooked the still more important fact, that the chemical

power of all bodies is augmented by every addition of caloric; and when Davy observed, that combustion was the solution of bodies in oxygen gas, he overlooked the fact, that all gaseous bodies are solutions of ponderable matter in caloric, without which they could not dissolve and combine chemically with other bodies.

It was maintained by Beccher and Stahl, that all bodies contained within them an exceedingly subtile, elastic and active principle, which they termed *phlogiston,* and which was disengaged during the process of combustion, producing the phenomena of *heat and light*, or *fire.* Many and long were the disputes of philosophers concerning the nature of phlogiston. While many maintained that it was a material substance, Lavoisier is supposed to have demonstrated that it was only an imaginary something, invented for the purpose of explaining the mystery of combustion. That Stahl regarded phlogiston as the cause of heat and inflammation, is evident from the etymology of the word, which signifies heat or fire.

From what is reported of Dr. Black's unpublished *Lectures on Respiration*, it would seem that he confounded *phlogiston* with the carbon secreted from the lungs; for he maintained, that a portion of atmospheric air unites with phlogiston in the lungs, and that animal heat was disengaged during the process. (*Leslie on Animal Heat.*)

The celebrated Scheele supposed that heat was composed of *phlogiston and empyreal air*, (oxygen,) and that light was composed of phlogiston and heat: while Kirwan supposed that *phlogiston* was identical with

inflammable air, (hydrogen.) Such were the vague and contradictory opinions of philosophers in regard to the nature of *heat*, *light* and *phlogiston*, during a great part of the preceding century.

After the discovery of latent heat by Dr. Black, and of oxygen by Priestley, the theory of Stahl was gradually superseded by that of Lavoisier. This celebrated chemist maintained that oxygen consisted of caloric and light, united with a ponderable base, and that during every case of combustion this base combined with the burning body, by which its volume was diminished; while the caloric and light of the oxygen were given out in the form of fire.

It is scarcely necessary to add, that this theory was also found to be exceedingly defective and erroneous in nearly all its essential conditions; that atmospheric oxygen is not indispensable to the process of combustion, nor the exclusive source of caloric and light; that all bodies contain definite quantities of caloric in a latent or combined state, and may be expanded into flame or light by a sufficient quantity of the same principle.* He was equally mistaken in supposing

* When carbon, sulphur, phosphorus, boron and the metals are heated in vacuo, they become luminous without the agency of oxygen. Another decisive proof that oxygen is not the only source of light is, that the colour of the flame varies according to the nature of the combustible. Hydrogen affords a bluish light; potassium and many other bodies, burn with a red light. Hence it is, that bituminous coal burns with a bluish light when only partially ignited, because the hydrogen alone is volatilized, while its carbon remains fixed. Hence also it is, that around the bottom of a candle flame, where the heat is not sufficient to ignite the carbon, there is always a circle of bluish light, which proceeds from the combustion

that the condensation of oxygen was always necessary to combustion.

It is doubtless true, that during the chemical union of gaseous oxygen with metals, its volume is greatly diminished, and a large amount of heat disengaged, by which the metals are expanded into the luminous state when the process is rapid. But it is equally certain, that the combustion of other bodies is attended with expansion instead of contraction of the combining materials, as illustrated in the third chapter, when treating of explosion and deflagration. It is here worthy of special attention, that while Lavoisier pointed out the vast abundance and importance of oxygen in combustion, respiration, acidification and fermentation, he did not explain the cause of oxidation, which is indispensable to a theory of combustion.

Nearly all the phenomena of chemistry may be referred to *combustion and solution.* Fermentation, respiration and putrefaction, are slow combustions, to which caloric is equally essential, as to every case of solution, liquefaction and vapourization. It is well known to every practical chemist, that water is generated by combustion; that nitrogen, carbon, sulphur, phosphorus, selenium, chlorine, iodine, boron, arsenic

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of hydrogen. When potassium is thrown upon water, it enters into a state of vivid combustion; the water is decomposed, and the metal expanded into red light. At the same time, a portion of the hydrogen thus decomposed, unites with the potassium, producing a beautiful purple and rose coloured flame; that is, the blue and red colours on combining produce a reddish purple. Query,—May not all the diversities in the colours of heterogeneous light resulting from combustion be thus accounted for in a very simple manner?

and some other bodies, have no affinity for oxygen at very low temperatures; but that when caloric is added in sufficient quantities, a rapid oxidation takes place, as in ordinary combustion, by which *acids* are generated — that when potassium, sodium, barium, lithium, calcium, magnesium and strontium, are heated in atmospheric air, they combine rapidly with its oxygen, forming *alkalies;* that when aluminum, glucinum, yttrium, thorinum and zirconium, are heated with oxygen gas, new compounds are generated, termed *earthy bases;* and that when the other metals are exposed to a high temperature, they are converted into acids or *metallic oxides.*

At the temperature of 32° F., oxygen has no perceptible attraction for iron. Hence it is, that in the polar regions, and during excessive winters in the middle latitudes, metals are not corroded by oxidation, but speedily acquire a coating of rust in tropical climates.* The process of oxidation augments with every addition of caloric up to the fusing point. It is therefore preposterous to maintain, that the attraction of metals for oxygen is owing to some inherent property of their particles, or that caloric operates merely by overcoming their cohesion, and thus enabling their chemical forces to come into play. So powerful is the attraction of iron for oxygen when raised to a white heat, that

* If a piece of cold polished iron be inserted into fluid mercury, there is little or no attraction exerted between them; but if the iron be made red hot before immersion, it acquires a coating of mercury, which adheres firmly. Even gold, which adheres to mercury at common temperatures, attracts it still more powerfully when heated, and so of other metals.

it takes it from potassium, which, at ordinary temperatures, is the most easily oxidized of all the metals. As the attraction of potassium for oxygen is known to be augmented by every increase of temperature, there is every reason to believe that its *latent caloric* is the primary and efficient cause of the chemical force by which it is enabled to decompose water, or even ice; and that if its temperature could be sufficiently reduced, its affinity for oxygen would be destroyed.

In accordance with this view of the subject, it is well known that phosphorus, sulphur and the most combustible compounds of hydrogen and carbon have no affinity for oxygen at very reduced temperatures, but attract it rapidly when assisted by heat. It would therefore be a waste of time to multiply proofs that caloric is the cause of oxidation. There is hardly a substance in nature with which oxygen may not be made to unite under the influence of heat.

Finding it impossible to overlook the agency of caloric in chemical affinities, Sir H. Davy maintained that "it gave freedom of motion to the particles of bodies, and exalted their electrical energies." (*Phil. Transactions*, Nov. 1806.)

It is also observed by Berzelius, that "a great number of bodies seem to possess but feeble affinities at ordinary temperatures of the atmosphere, which acquire very active powers of attraction when raised to high temperatures." (*Des Proportions Chimiques*, p. 57.)

This illustrious chemist might have added, that the chemical power of all bodies is exalted by every addition of caloric, and diminished by its abstraction. All

the destructions and regenerations of matter may be referred to that law of caloric by which it repels its own particles, and attracts those of ponderable matter. By its self-repulsive property, caloric dissolves, expands and decomposes all things; by its affinity for ponderable matter it contracts, unites and holds together all things; thus causing the centrifugal and centripetal forces of nature. By the agency of heat, chlorine, fluorine, iodine and bromine, are made to combine with sulphur, phosphorus, metals, &c. by which new compounds are generated, termed chlorides, fluorides, iodides and bromides. When carbon, sulphur, phosphorus and other bodies are heated with metals, they are converted into carburets, sulphurets and phosphurets. By the agency of solar heat the oxygen of the atmosphere is made to combine with the elements of dead animal and vegetable matter, which are thus constantly undergoing a slow combustion or dissolution during summer, by which new combinations are formed.

It has been said that iron and other metals may be kept in a state of *ignition* for unlimited periods of time without any loss of their substance. Nothing could be more unfounded. The truth is, that the incandescence or luminosity of all bodies, *cæteris paribus*, is in proportion to temperature; while they are vola tilized and dissipated in the same ratio. When iron is raised to a red heat, the oxygen of the air combines with it, as in cases of ordinary combustion, by which the process is kept up; but if they are heated in vacuo, the ignition ceases when the heat is withdrawn, because there is no oxidation.

It is necessary to distinguish the *quantity* of light produced by combustion from its *intensity*. When lime, magnesia and many other fixed bodies are submitted to the high temperature of an oxy-hydrogen blow-pipe, they are slowly dissipated, with the disengagement of a most dazzling and intense light, but in small quantity; whereas, if ether, alcohol, naphtha, wax, tallow, oils, resins, phosphorus, sulphur, cotton, paper, silk and many other inflammable compounds, are submitted to one-third of the above temperature, a far greater quantity of light is produced, but of much less intensity: yet Dr. Lardner observes: "there is reason to believe that all bodies begin to be luminous when heated, at the same temperature." (*Treatise on Heat*, p. 24.) On the other hand, when charcoal is exposed to the concentrated heat of a large voltaic battery, it is expanded into light, which in splendour almost rivals that of the solar beams; yet not in such great quantity as during the process of ordinary combustion, by which more carbon is ignited. The concentrated heat of a forge while acting upon iron and other metals that are difficult to volatilize, creates a light so intense, that it strikes upon the eye-balls like finely comminuted sand. But the same degree of heat acting upon an equal weight of oil, wood or bituminous coal, would produce one hundred times the quantity of light, though of much less intensity.

That modification of light termed *phosphorescence*, is generally the result of a slow combustion. Being produced at very low temperatures, it is both *small in quantity, and of low intensity.*

From all the preceding facts and observations it would appear,—

1. That the heat of combustion results from the disengagement of that principle which holds the particles of bodies together; and that what is called the polarity of atoms, or the electro-positive and negative conditions of matter, depend upon its plus and minus relations to caloric.

2. That the attraction of caloric for ponderable matter is modified by every chemical change which the latter undergoes, whether of combination or decomposition, contraction or expansion.

3. That the light of combustion or flame, results from the ultimate division of ponderable matter by caloric, which is diffused in all directions by radiation with extreme velocity; and that without the volatilization of combustible matter, there could be no artificial light.

CHAPTER III.

CHEMICAL SOLUTION.

"Veniet tempus quo posteri nostri apperta nos nescisse mirenter."—SENECA.

COULD we take in at one view the whole system of nature, we should behold, throughout, one vast theatre of solution and crystallization, of decomposition and recombination. We should perceive, that the atmosphere always contains an immense quantity of water diffused through it in a state of invisible transparent vapour, until it meets with colder currents of air, when it is condensed and precipitated in the form of rain, snow or hail, by the abstraction of its solvent principle. All lakes, rivers and springs contain greater or less proportions of the rocks, salts and metals, that compose the crust of the earth through which they pass, in a state of chemical solution; that are carried down by running water and deposited on different parts of the great "ocean floor."

We should observe many thousand hot springs, issuing from the sides of mountains and from the bottom of the sea, charged with enormous quantities of earthy and metallic bodies in solution; which are precipitated as they cool down, forming new strata of rocks and earthy deposits.

Could we look through the earth as through a great crystal, and behold all its molecular motions and changes, as we do the formation of a salt by the aid of an oxy-hydrogen microscope, we should be transported with admiration of a scene at once so grand, simple and beautiful. The exquisite mechanism by which crystals are generated, is carried on by the regular arrangement of atoms in series and aggregates, the forms of which are determined by the most exact mathematical laws, by the adjustment of atoms, far too small to be discerned with the most powerful microscope. During the crystallization of a drop of muriate of ammonia, magnified three million times, and reflected on a large white ground, many thousand small crystals are seen shooting in every direction as the solution evaporates, which coalesce and form one solid crystal. Still more admirable is the process of organization by which the particles of water, air, carbonic acid, ammonia, &c. are converted into plants and animals, endowed with irritability, sensibility and the power of attracting nourishment for their support; while solution or fluidity is essential to every vital process.*

* A complete history of the Mississippi river would afford an instructive example of the power of water in slowly dissolving rocks and transporting them to distant regions. Receiving, as it does, many large tributaries, that are fed by a thousand smaller streams, which drain more than a million square miles of territory, they pass through every variety of rocky strata. Some of its largest tributaries, such as the Ohio, Missouri, Kentucky, Cumberland and Tennessee rivers, meander through extensive regions, based on secondary limestone, which extends, with occasional interruptions, from Alabama to the Falls of Niagara; and varying from

That caloric is the universal solvent of nature is evident from the fact, that it converts all solid bodies into liquids and gases or vapours, which are reconverted into solids by its abstraction. It is equally clear, that if caloric be the cause of all liquidity and vapourization, it must be the menstruum by which liquids and elastic fluids are enabled to dissolve other bodies.

The most remarkable facts connected with solution, may be reduced to the following propositions:—

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500 to 2000 feet in depth. Through these immense beds of ancient limestone, they have furrowed channels from 200 to 500 feet deep. By their chemical solvent power, hundreds of subterranean caverns have been gradually formed in the long lapse of ages, with all those beautiful calcareous crystals termed stalactites, with which many of them are so gorgeously decorated. All valleys and river beds are slowly formed by the chemical and mechanical agency of running water. Many springs also contain in solution large quantities of carbonate of iron, which, as well as lime, makes a cement that binds into solid masses the beds of loose sand through which they pass, forming sandstone. Were we to follow out this subject in a geological point of view, we should find that a great portion of the solid materials that have been thus removed from the numerous valleys drained by the Mississippi, have been transported to the Gulf of Mexico, which it is slowly filling up; while the rest is conveyed by the Gulf Stream into the wide Atlantic to form new rocks, after having travelled thousands of miles in a state of invisible solution. The amount of soil, gravel and sand which are washed down from mountains, hills and plains into the valleys during floods of rain is enormous. A large proportion of Louisiana, which contains about 48,000 square miles, is composed of vegetable mould, pebbles, gravel, sand and clay that have been conveyed by this great river into the Gulf of Mexico. Immense masses of floating trees are also deposited on its banks and islands and at its mouth, which are covered by sand and clay, where they will be gradually converted into beds of coal. Thus it is that everything in nature is in a state of perpetual transition and revolution.

1. That all fluids are chemical combinations of caloric with ponderable matter. Water is composed of oxygen, hydrogen and caloric; sulphuric acid of oxygen, sulphur, water and caloric, and so of other liquids, the elements of which are chemically combined with it in definite proportions:

2. That no solution of a solid in a fluid ever takes place, without a transition of caloric from the solvent to the solvend:

3. That the solvent power of water and other menstrua is exalted by caloric and diminished by its abstraction:

4. That the solutions of animal, vegetable and mineral substances in water and other liquids, are strictly chemical combinations.

These propositions being admitted, it follows, according to the most rigid principles of logic, that if caloric be the cause of solution, it must also be the cause of chemical attraction, by which salts, rocks and metals are held in a state of intimate combination with liquid menstrua.

It may be objected, that caloric is not the universal solvent of nature, because lime and magnesia are more soluble in water at 60° F. than at 212°. But if it be true that lime and magnesia, like all other bodies, are dissolved in unlimited proportions by hot springs, such exceptions disappear, and therefore cannot invalidate the general fact.

It is stated by Mr. Lyell, to whom the science of geology is very largely indebted, that the warm springs which supply the baths of San Filippo, near Rome, contain in solution so large a quantity of calcareous

and magnesian rocks, that they have been known to deposit in a pond a mass thirty feet thick in twenty years. (*Principles of Geology*, vol. i. p. 204.)

Mr. Lyell seems to suppose that the carbonic acid contained in hot springs, is the chief cause of their solvent power. But it is well known that sulphate of lime and many other rocks, are dissolved by hot springs without the aid of carbonic acid. It is therefore evident, that the solubility of lime and magnesia is augmented by heat, as certainly as that the fusibility of all other rocks and metals is augmented by it. It is highly probable, that the carbonic acid found in hot springs, has been driven off from a state of combination with lime by the agency of intense heat. Few geologists are aware how large a proportion of the calcareous, magnesian and silicious rocks distributed over our planet, have been deposited from hot springs. Mr. Lyell has shown, that various parts of Italy and Sicily are covered over by strata of limestone thus formed, several hundred feet deep in many places.

It is impossible to have enlarged views of chemical science, if we confine our observations to the petty operations of an artificial laboratory. Those who do so tell us that silex is insoluble, or nearly so, in water. But those who look to the great laboratory of subterranean chemical action, where the heat is far more intense than man can produce, will find that silex is there dissolved as copiously as sugar in boiling water; and that it is deposited in vast quantities by hot springs, such as the geysers of Iceland, the *valle das furnas* of St. Michael and innumerable others that

issue from volcanic regions, forming opal, chalcedony and various silicious gems.

The flinty deposits found in the chalk-beds of Europe have doubtless been derived from submarine hot springs. Many of the marine fossils found in the chalk are composed of silica,—a fact which cannot be otherwise accounted for.*

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* It is related by Mr. Barrow, in his *Visit to Iceland* in 1834, that the streams which proceed from the geysers of Iceland deposit a white silicious rock, of a close compact texture, resembling white marble. This is an exceedingly interesting and important fact to the geologist. The author was once greatly embarrassed on finding beautiful strata of perfectly white silicious rocks, which had been obviously deposited from water, inclosed between masses of basalt, greenstone and other volcanic rocks in the mountains of North Carolina, more than 4000 feet above the ocean level. As all the other portions of those mountains consisted of granite, gneiss, porphyry and other igneous rocks which had been elevated by subterranean heat, the existence of the white sedimentary rocks remained a mystery, until the agency of hot springs was investigated.

The geysers rise up through volcanic rocks, in an island where the eruptions of lava are so enormous as to fill up gorges many hundred feet deep and two hundred feet wide. When not confined in narrow valleys, they expand into broad lakes of melted rocks that vary in thickness. Were such eruptions to cover the white silicious strata deposited by the geysers, (as they undoubtedly have done, and will do again,) they would be inclosed between igneous rocks, like the snow-white flinty strata in the mountains of North Carolina. All animal and vegetable petrifactions composed of silex have been doubtless formed in waters holding this mineral in solution, from the most minute animalcules and delicate moss agates, to the largest fragments of silicified wood. Mr. Barrow states, that on the margins of the numerous little streams in the neighbourhood of the great geyser, every description of wood, bones, the horns of animals, and even paper, worsted stockings, handkerchiefs, &c. were found in a silicified state.

It is stated by Gay-Lussac, that the solubility of sulphate of soda in water, is augmented by every addition of temperature from 32° to 91·4°, and then diminishes up to 212° F. (*Ann. de Chim. et de Phys.* xi. 296.)

It has been also said, that chloride of sodium (common salt) is not more soluble in water at 212° than at 60.° Whatever may be the cause of such anomalies, they do not afford the slightest proof that caloric is not the solvent, for this plain reason, that when a solution of common salt is exposed to great cold, it is precipitated and the water becomes nearly fresh; that is, when the agent which held it in a state of chemical combination with the water is withdrawn, it falls down; which clearly proves that the chemical attraction of water for the salt is owing to its caloric. Hence it is, that sea water is deprived of nearly all its salt by congelation, as demonstrated experimentally by Danes Barrington,—a fact which the author has seen verified on a large scale. In the month of January, 1834, when the Bay of New York was frozen over, the ice that covered it was found to be but slightly brackish. It is therefore evident, that if the ocean could be frozen

The steam emitted from volcanos is charged with a great variety of rocks, salts and metals in a state of solution, which are deposited in the crystalline form as the solutions cool down. When melted silex cools under the pressure of a mass of lava, making rock crystal, a portion of steam is sometimes inclosed within its centre and condensed into water, where it remains for unlimited periods of time. All geodes are probably formed by the cooling down of lava, that contained steam or other gaseous fluids within their interior, which, escaping by percolation, if the rocks be porous, had left their centres hollow.

throughout, it would not be capable of holding its salt in a state of chemical combination, but that it would fall to the bottom, constituting a solid stratum, varying in thickness with the depth of the ocean. Dr. Turner states, that common salt dissolves in twice and a half its own weight of water at 60°; from which, and the preceding facts, it follows, that if the ocean were saturated with salt and afterwards frozen, it would deposit a stratum more than one-third its depth.

It is likewise obvious, that the tropical ocean must contain more salt in suspension than the Polar seas, especially during winter, and in the vicinity of icebergs or other frozen masses.*

If it be maintained that caloric is not the solvent of sulphate of soda, lime and magnesia, because they are more soluble in water at 60° than at 212°, the same mode of reasoning would prove that caloric is not the solvent of sulphur, which is well known to be perfectly liquid at 230° F., but becomes viscid at 300°, and continues so up to 400°. In reply to such objections, it may be stated in the first place, that no chemical union ever takes place until one at least of the combining bodies is reduced to the fluid state, and that caloric is essential to all fluidity: secondly, that the chemical force by which water is enabled to dis-

* It can hardly be denied, that sugar is chemically combined with cider by the agency of caloric; for it is well known that during the congelation of sweet cider, its sugar falls down, and may be found at the bottom of the vessel which contains it, in the state of a highly concentrated syrup. But if afterwards exposed to warmth, it is again taken up and recombined with its watery solvent, which thus acquires its original properties.

solve and combine with animal, vegetable and mineral substances, is exalted by every addition of temperature, in a thousand cases for one exception. And I have shown that the above examples afford no real exceptions to the principle, but confirm it; that sulphate of soda and common salt are far more soluble in water at 60° than at 32°; that lime and magnesia are perfectly soluble in hot springs, which owe their solvent power to intense subterranean heat.

Berzelius supposes that the greater solubility of lime and magnesia in cold than boiling water, is owing to a portion of carbonic acid that is almost always found combined with cold water; but which is driven off at a high temperature. Whether this be regarded as a true explanation of the fact or not, it is generally admitted by chemists, that carbonic acid augments their solubility in water. This however does not fully resolve the problem, since the solubility of sulphate of soda increases with the temperature from 32° to 91·5° F., and then diminishes slightly, up to 212°.*

Dr. Arnott admits, that the solution of a solid in any gas or fluid menstruum is merely another mode of melting it by heat; and that the menstruum itself is fluid only because of the heat which it contains. (*Elements of Physics*, vol. ii. p. 47.)

This is a true statement as far as it goes; and it is highly probable, that if this philosopher had renounced the *inherent attractive properties of atoms*, as Newton did on second thoughts, he would not have added the

* M. Lassaigne has recently shown that water saturated with carbonic acid dissolves more carbonate of lime at 50° F. than at 32°. (*Journ. de Ch. Med.*, Fevrier, 1847.)

following sentence. "A menstruum dissolves other bodies, merely because its attraction for them brings their particles into union with the heat which already exists in it." Why then should water at 212° exert a stronger attraction for salts than water at 32°? Why should hot water ascend through porous solids and capillary tubes more rapidly than cold water? Why should boiling water dissolve 18 times more nitrate of potassa than ice-cold water? and 20 times more chlorate of potassa? Why should boiling water attract and dissolve, or combine chemically with the aromatic constituents of tea, coffee and a thousand other vegetable products, more rapidly than cold water, if caloric be not the combining agent? or why are the chemical affinities of all bodies modified by every addition and subtraction of caloric, if it be not the ruling principle of action in all solutions?

That *caloric* is the medium by which water is enabled to combine chemically with salts, will appear from another view of the subject. For example, *those salts for which caloric has the greatest affinity, have also the strongest attraction for water.* The consequence of which is, that they absorb it from the atmosphere, producing what is termed their deliquescence; and when dissolved in water they absorb its caloric, by which cold is produced.

It is likewise owing to the powerful attraction of caloric for such salts, that when dissolved in water they are so difficult to congeal; that is, they require an intense degree of cold to abstract from them that portion of caloric which maintains them in a state of chemical combination with water. When I come to

treat of freezing mixtures, it will be seen that solutions of potassa and chloride of lime, formed by mixing them with snow, remain liquid at 82° and 83° below the freezing point of water.

The same thing is true of many other salts, though to a less extent. It is owing to the attraction of caloric for common salt, that sea water will not freeze at 32°, but requires a further reduction of temperature to produce the effect, when it gives up a portion of its heat and the salt falls down. When 30 per cent. of common salt is dissolved in water, its freezing point is reduced to 0°. Moreover, the cohesion of the solution is so far augmented, that its boiling point is raised to 224° F.

In like manner, all those salts for which caloric has a strong attraction, and therefore produce cold during their solution, elevate its boiling point; such as nitrate of potassa, nitrate of soda, acetate of soda, tartrate of potassa, muriate of ammonia and many others.*

Dr. Lardner states, that the solution of a salt in

* It is owing to the affinity of caloric for sulphate of soda, that when dissolved in hot water, and tightly corked up in a phial, it cools down without crystallizing, if kept perfectly still. But if shaken, a portion of the caloric which held it in a state of combination with the water is disengaged, when the phial becomes warm, and the solution crystallizes. If the cork be withdrawn, the same effect is produced, owing to the mechanical pressure of the atmosphere, which forces out of the solution a portion of its caloric. By inserting into it a piece of ice, or any salt that has an affinity for caloric, crystallization is produced, for the same reason that all other fluids are congealed by the abstraction of their caloric. It has been said that a film of oil retards the crystallization, which is no doubt the fact, because it is a bad conductor of caloric, and therefore prevents its ready escape.

water *diminishes the cohesive force of the liquid*, and therefore lowers its freezing point. (*Treatise on Heat*, p. 194.)

The fact however is just the reverse, for a saturated solution of chloride of calcium in water requires 42° more caloric to overcome its cohesion than pure water; that is, it requires a temperature of 264° F. to make it boil. In other words, the particles of water, which are held in a state of chemical union with the salt by caloric, have a stronger attraction for the particles of chloride of calcium than for each other; therefore they cannot be separated and driven off in the form of vapour without an augmentation of temperature.

From the preceding facts and observations we are brought to the general conclusion, that the deliquescence of salts, the production of cold during their solution in water, the low temperatures at which they congeal and the high temperatures at which they boil, are all determined by their relations to caloric, which holds them in a state of chemical combination with water.

THEORY OF FREEZING MIXTURES.

It was before stated that no solution of a solid in a liquid ever takes place without a transition of caloric from the solvent to the solvend. The truth of this proposition is strikingly illustrated by the phenomena of freezing mixtures.

When water is congealed into snow or ice, caloric has a stronger affinity for it than in the liquid state. Hence it is that when a pound of water, at the tem-

perature of 172° F. is mixed with a pound of ice or snow, the latter is dissolved, and the mixture brought to the temperature of 32°; proving that 140° of caloric have passed from the water to the snow, and intimately combined with it during the process of liquefaction.

But there are many salts which abstract caloric from snow, by which they are dissolved, or chemically combined with the snow. Such is the affinity of caloric for common salt, that when mixed with its own weight of snow, both at the temperature of 32°, there is a transition of caloric from the snow to the salt, by which they are intimately united, and the temperature of the mixture reduced 41°. Again, so powerful is the attraction of caloric for chloride of calcium that when three parts of the latter are pulverized and mixed with two of snow, both at 32°, the temperature and congealing point of the mixture are reduced —50°: and if four parts potassa be mixed with three of snow, the temperature falls —51°, or 83° in all. But if two parts chloride of calcium and one of snow be reduced to —9°, and put into the solution of snow and salt, the temperature and freezing point of this new mixture are reduced to —74°.

That there is a transition of caloric from snow to such salts, is evident from the fact, that if the chloride of sodium and snow be cooled to —9°, and then mixed together, no solution or further reduction of temperature takes place; and that if chloride of calcium and snow be cooled from 32° to —50° before they are mixed, no chemical solution, nor change of tem-

perature occurs, because there is no transition of caloric from one to the other.

Many other salts have the power of absorbing caloric from water, acids and from snow, such as nitrate of potassa, nitrate of soda, hydrochlorate of ammonia, chloride of zinc, sulphate of soda, &c. If nitrate of ammonia be pulverized and mixed with its own weight of water, at 50° F. the temperature is reduced 46°; that is, down to 4°, which is 28° below the freezing point of water; and if the same quantity of carbonate of soda be added, the temperature is reduced to —7°, or 39° below 32°. If then such salts can abstract caloric from liquids at 4°, and even below zero, it follows *à fortiori*, that they can take it from snow at 32°.

Dr. Turner observes, that when salt and snow are mixed, the salt causes the snow to melt by reason of its affinity for water. But if the snow and salt be cooled down to —9°, there is no attraction between them, and therefore no solution nor reduction of temperature. Nor is it a fact, as stated by Dr. Thomson, that every mixture which generates cold, contains a considerable quantity of water in the solid state; for hydrochlorate of ammonia contains none, and the nitrate of ammonia only 1¼ per cent. So of many other salts. The truth is, that all freezing mixtures are dissolved by caloric as certainly as that snow is dissolved by boiling water; for the simple and sufficient reason, that caloric is indispensable to all fluidity, without which there can be no chemical combination. "*Corpora non agunt, nisi sint soluta.*" When snow is dissolved in the strong acids, there is a rapid transition of caloric from the acids to the snow, by which

they are chemically combined, with a reduction of temperature, as in the solutions of ice or salts in water. If eight parts of snow be dissolved in five of hydrochloric acid, the temperature of the mixture is reduced 59°; and if seven parts of snow be dissolved in four parts of diluted nitric acid, the mixture falls to 62°. The same effects are produced by mixing pulverized salts with the strong acids.*

After having proved that caloric is the universal solvent of nature, and that solution is strictly a chemical process, it would be needless to insist that the strong acids owe all their chemical properties to the heat which is combined with their atoms. Like all other liquids, they are solidified by the abstraction of caloric, and when frozen, their burning caustic properties are greatly impaired, together with their powers of combining with other bodies.† This view agrees with the etymology of the word caustic, which was

* It is said that the best of all freezing mixtures is one composed of four ounces carbonate of ammonia, four ounces subcarbonate of soda, and four ounces of water. This mixture will convert ten ounces of water, contained in a tin vessel, into ice.

† When this subject shall have been more fully investigated, it will be found that the melting point of tin, bismuth and lead, when united into an alloy, is reduced for the same reason that the melting point of chloride of sodium, chloride of calcium, potassa and other salts, is lowered on mixing them with snow. This would appear from the fact, that when 217 grains of lead, 118 of tin, and 284 of bismuth, are finely powdered and mixed with 1617 grains of mercury, the temperature of the mass falls from 64° to 18° F.,—proving that there is a transition of caloric from one to the other; which is true, in fact, of all chemical changes. Besides, when three parts lead, two of tin, and five of bismuth, are pulverized and mixed together, they melt at 197° F.

derived from the Greek noun καυσις *causis*, Heat, or from the verb καυσω *causo*, I will burn.

It may be regarded as a fundamental axiom in science, that the laws of nature are uniform throughout all her diversified changes and revolutions. Whatever hypothesis is opposed to this great principle, should be at once rejected as unsound.

Some modern philosophers, of high reputation, have taken a different view of this important subject. In his late *Bridgewater Treatise*, Dr. Prout observes, that "the world itself before arriving at its present condition, has not only undergone a progressive series of different states, but in these different states, *different laws of nature* have prevailed." (Book I. Section 4.)

It is also maintained by the Rev. Mr. Lloyd, that "the forces by which the world was brought into its present form, were originally far more energetic, before the appetences of matter for matter had been so extensively satisfied. Shall we expect (he adds) to find the same activity in a neutral salt, as in its separate elements before chemical combination?" (*Transactions of the British Association* for 1835.)

In answer to such hypotheses, it may be affirmed, that the aggregate amount of force and motion in the universe never varies; and that if the laws of nature were not always the same, there could be no established principles of science. Old things pass away and all things become new, but the properties and laws of the primitive elements never change. Memphis and Thebes, Nineveh and Babylon, Balbec and Jerusalem, with their gorgeous palaces and solemn temples, have passed into other forms of existence—

yea, the "everlasting mountains" have silently mouldered into ruins, and been transported to other regions; but nature retains forever the same youthful energy as in the morning of creation. The "sun himself may waste away, grow dim with age," and pass into other modes of existence; still, there is not the slightest evidence that the primitive constituents of matter ever change.

If then it be true that caloric is indispensable to the existence of gaseous oxygen, and to its combination with other bodies, as in combustion, fermentation and putrefaction—to the generation of water, and its power of uniting with salts, it must be equally essential to the generation of acids, and to their chemical combination with the alkaline, earthy and metallic oxides, as in the formation of salts and rocks.

It is quite evident, that all solid bodies have been formed from a state of chemical solution. Volcanic rocks have been formed from a state of fusion by subterranean caloric; while sedimentary rocks have been formed from a state of solution in water; and I have proved that the solvent power of water is owing wholly to caloric; since those bodies which are insoluble in cold or even boiling water, become so at still higher temperatures.

It was observed by Lord Bacon, that "we should inquire how far infusions may be made, by the help of attractions." The truth is, that all infusions, like the solutions of salts in water, are obtained by the attractive agency of caloric. The familiar process of drawing teas depends simply on the attractive power of

heat, to which we owe all our infusions, medicinal extracts, emulsions, &c. The superior cleansing property of hot over cold water, is owing to its power of combining chemically with the various impurities that adhere to clothing, &c. It is also known that metals are deprived of their drossy combinations, and thus purified by the agency of heat. Hence, among the nations of antiquity, it was regarded as the type of *purity;* a term derived from the Greek word πυρ, signifying heat or fire. Cold water has no attraction for tallow, butter and other oily substances; but the cook understands practically, that when water is raised to a boiling temperature, it will extract and combine with the gelatinous and oleaginous ingredients of animal bodies, making soups and gravies; which proves that the combining power is not in the water, but results from the agency of heat.

The chemical power of water is so far exalted by caloric, that when raised to the temperature of 400°, as in Papin's digester, it dissolves nearly all animal matters, together with the oily and resinous portions of wood, which are but slightly soluble in boiling water.

Caloric enables water to combine with salts and the various ingredients of organic compounds, for the same reason that it enables atmospheric oxygen to unite with wood, coal and all other combustibles, including the metals; and for the same reason that it enables melted metals to dissolve and unite with solid metals.

All solutions of salts in water, or metals in acids, are the results of an attraction between the solvent and the solvend. But if this attraction augment with

every addition of caloric, it cannot be an inherent property in the atoms of the menstruum.

Nothing could more strikingly illustrate the immense aggregate force of chemical attraction than the phenomena of solution. For example, it is well known that when sugar or salts are dissolved in water, and metals in acids, the liquids undergo very little augmentation of volume; consequently, their density must be greatly increased. But it is evident from the experiments of Perkins, that a mechanical pressure equal to 2000 atmospheres, is not capable of reducing water more than one-twelfth of its volume, if so much. What then must be the force of attraction by which salts and metals are united during the process of chemical solution? By the transition of caloric from liquids to solids, the latter are dissolved and chemically united, with diminution of volume, for the same reason that the bulk and elastic force of gases are lessened on combining chemically.

The force of chemical attraction is equally evident from the manner in which it overcomes the cohesion of solid bodies. The attraction of nitric acid for the atoms of silver, copper and iron, must exceed that of their cohesion; for it tears them asunder, but in an almost imperceptible manner, and atom by atom.

It was before shown, that when tin, lead, copper, silver and other metals, are converted into the liquid state by heat, their power of combining with each other is greatly augmented; and that whenever a melted metal unites with a solid metal, there is a transition of caloric from the one to the other.

In like manner, when mercury, gold, silver, &c. are

converted into vapour, under plates of copper, iron and other solid bodies, there is a transition of caloric from the former to the latter, by which the particles of metallic vapour are transported to, and intimately combined with the solids, for the same reason that melted tin unites chemically with copper and iron vessels when poured into them, as in the process of tinning; or for the same reason that aqueous vapour is attracted by cold bodies, and combined with them in the form of dew or frost; that is, by virtue of an attraction of their caloric for bodies that contain less of it.

But if the attractive power of all bodies be modified by every change in their relations to caloric, it is unphilosophical to refer the effect to electricity, unless it be a modification of caloric; and still more so to confound attraction with the innate properties of gross matter.

That the strong acids owe their activity and chemical properties to caloric, is evident from the following facts:

1. They all become solid by the abstraction of caloric, when their burning caustic properties are greatly diminished, together with their power of dissolving other solid bodies.*

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* Since the London edition of this work was published, M. de Mareska has found by experiment, that at —112° F., sulphuric acid no longer reddens litmus, and does not act upon the alkalies, the carbonates, iodide of potassium, nor chlorate of potassa. He also found that bromine, iodine and sulphur, combine with liquid chlorine at —90° F.; that when powdered antimony is put into liquid chlorine at the same temperature, they combine with evolu-

2. Their power of dissolving metals is greatly augmented by raising their temperature.

Concentrated sulphuric acid acts very feebly on iron, until made boiling hot. Copper is dissolved rapidly by sulphuric acid when raised to the boiling point. Lead, which is not affected by sulphuric acid when cold, is readily dissolved by it at 212° F. Its solution in nitric and acetic acids is also greatly augmented by raising their temperature. But it would not be philosophical to maintain that an agent which is indispensable to all fluidity, and which increases the solvent power of acids, is different from the primary and efficient cause of solution.*

3. When the earthy, alkaline and metallic oxides are dissolved in the acids, they are chemically united with them, and thus maintained in a state of transparent solution, like salts in water, in opposition to their specific gravity; and may be crystallized by evaporation or by cold.

When salts, rocks and many metals, are converted into the liquid form, whether by the direct agency of caloric alone, or by means of a chemical menstruum,

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tion of heat (and light?). But that if dry chlorine gas be brought in contact with antimony placed in a tube, and the latter be inserted in solid carbonic acid, (which congeals at —148° F.,) no action is produced. (*Silliman's Journal*, March, 1846, p. 256.)

* The first part of the process by which metals are dissolved in the strong acids, is decidedly one of combustion. For example, when nitric acid is poured upon plates of iron, copper, &c. a portion of its oxygen unites chemically with them, by which they are converted into oxides, with disengagement of heat, (as when poured on volatile oils, and other inflammable bodies,) after which, they are dissolved like salts in water.

their particles arrange themselves in regular series, at various angles, forming symmetrical aggregates, that cohere in definite forms as they cool down. When sulphur, iodine, camphor, benzoic acid, with many other simple and compound bodies, are converted into the gaseous state, they also crystallize in regular forms on cooling down, like solutions of salts in water, or metals in acids.

From some recent experiments performed by M. Bequerel and Mr. Cross, it has been supposed that electricity is the agent by which crystals are aggregated. But if electricity be regarded as a distinct agent, *sui generis*, and the only cause of crystallization, why do water and other liquids assume the solid and symmetrical form on merely reducing their temperatures? There can be no doubt, that when a current of voltaic electricity is directed for days, weeks and months, upon salts and rocks, as in the experiments of Mr. Cross, it decomposes and transports their elements to the extremities of the battery, where they will assume the crystalline form. But it is equally certain, that crystallization is constantly going on in the laboratory of nature, where no electric action can be detected by the most delicate tests. The whole of this problem is resolvable into one of still higher importance and generality; that is, whether electricity be only a modification of that universal principle of action, which I have endeavoured to show, is capable of producing all the contractions and expansions of matter.

As yet, philosophers are but partially acquainted with the circumstances which determine the numerous

diversities in the forms of the same substance: why, for example, there should be above 600 modifications in the crystalline arrangement of carbonate of lime? But it has been ascertained by the recent researches of Mitscherlich and Haidinger, that various proportions of water unite with many substances at different temperatures, during the process of crystallization, producing a corresponding diversity of forms; that seleniate of zinc unites with three different portions of water, and assumes three different forms, *according as its temperature is cold, lukewarm, or hot;* and so of other solutions. They also found that moderate degrees of temperature, such as that of the solar rays, produced a decided change in the molecular arrangement of solid crystals. It is equally certain that the crystalline form of snow and many other bodies, varies according to the temperature at which they become solid, and depends on the different quantities of caloric around their particles, the arrangement of which is thus modified. (See *page* 101.)

When it shall be clearly explained why sugar, gums, starch, gelatine, albumen and many salts, are more soluble in water than in alcohol; why sulphur, phosphorus, resins, &c. are more soluble in alcohol than in water; why some bodies are soluble in ether and oils that are insoluble in other liquids; why one acid dissolves metals which another will not; and why some metals are more soluble in diluted than in concentrated acids; the obscurities of chemical science will rapidly disappear. Again, why are resins soluble in the fixed oils; the latter in the volatile oils; and both of them in ether? Is it not because there is a

transition of caloric from the smaller particles of the latter, to the larger particles of the former, just as there is from the particles of snow and powdered ice to those of common salt and other freezing mixtures? Why do the volatile oils have a pungent taste, and redden the skin, while the fixed oils are nearly insipid, inodorous, and do not heat the skin? Is it because the former contain little or no oxygen, and therefore when diffused over the skin, tongue or olfactories, undergo a slow combustion; whereas the fixed oils require to be decomposed by a higher temperature before the carbon and hydrogen can unite with atmospheric oxygen? Certain it is, that the volatile oils, like ether and alcohol, take fire at much lower temperatures than resins or fixed oils.

That caloric is the universal solvent, without which liquids could not combine chemically with solids; we must endeavour to resolve the remaining difficulties, by carefully investigating the circumstances which determine the relative attractions of caloric for different bodies, and its transition from one to another.

Between water in the state of ice, and tallow, or oils, there is no affinity whatever. But when water is raised to the boiling point, it unites readily with all oleaginous substances; and at still higher temperatures dissolves resins, and various other bodies. The solubility of sulphur and phosphorus in alcohol is also augmented by raising its temperature.

All solutions and precipitations are owing to the transition of caloric from one body to another. What is termed elective affinity is owing to the stronger attraction of one body for caloric than another. By the

solvent power of caloric in nitric acid, it is enabled to combine chemically with silver, the particles of which are diffused equally throughout the menstruum, making a transparent solution of nitrate of silver. But if a portion of mercury be poured into the solution, the silver is precipitated as the mercury dissolves. It therefore follows, that if the caloric of nitric acid enabled it to dissolve and combine with the silver, it must have a still stronger attraction for the particles of mercury, or it would not desert the atoms of silver for them; in short, that the silver is separated from its combination with the acid by an abstraction of caloric, for the same reason that salts dissolved in water are precipitated by a reduction of temperature.

The same principle must apply to all other elections and precipitations, modified, however, by circumstances which require a careful investigation.

Lead precipitates mercury, and copper lead, which is again thrown down from a state of combination with nitric acid by iron; all of which changes are attended with transitions of caloric from the solvent to the solvend.

The art of coating metals with other metals by precipitation, is founded on the above law, such as gilding, silvering, tinning, &c. If a plate of copper or iron be immersed in a solution of nitrate of mercury, a coating of the latter metal is precipitated on them, for the same reason that aqueous vapour is precipitated on cold bodies, and coheres to them in the form of frost or ice. If nitrate of silver be dissolved in water and a plate of clean copper be inserted into the solution, a beautiful coating of silver is precipitated on the

copper; or, if a polished iron rod be immersed in a solution of chloride of gold, the latter is precipitated on it in the metallic form, for the same reason that melted tin, zinc, bismuth, silver, &c. are attracted by solid metals and thus chemically united with them, as in the process of plating. Hence it follows, that if caloric be indispensable to the solution of metals in acids, their precipitation must be owing to its abstraction by the solid metals.

From a general view of the preceding facts and observations, it is evident that caloric is the cause of all oxidation; that water and the strong acids are generated by its agency and chemically united with the earthy, alkaline and metallic oxides, forming salts and rocks: in short, that combustion, fermentation and solution are modified effects of the same cause.*

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* Mulder observes, that at temperatures from 59° to 67° F., when yeast is added to sugar, fermentation is brought on, by which alcohol and carbonic acid are produced. But when made to ferment at temperatures from 97° to 104°, other products are formed. He further states, that a definite temperature is required to convert alcohol into oxide of ethyl and water by means of sulphuric acid, which at other temperatures converts starch into gum and sugar; that one portion of caloric causes three, and another portion five equivalents of oxygen to unite with the same substance, forming phosphorous and phosphoric acids. He also maintains that the influence of caloric may be traced in nearly all catalytic phenomena; that the commencement of decomposition in yeast is attributable to a determinate catalyzing *temperature;* in fine, that "Heat is the pulse of life in the chemical changes of bodies, and has thus an unlimited influence upon their chemical combinations." (*Chemistry of Veget. and An. Physiol.*, pp. 34, 43, 44, 45, 46.) He observes in another place, that "the primary source of all chemical action must be referred to temperature."

CHAPTER IV.

CAPILLARY ATTRACTION.

> That very law which moulds a tear,
> And bids it trickle from its source,
> That law preserves the earth a sphere,
> And guides the planets in their course.
>
> ROGERS.

CONSIDERED in all its relations and bearings, capillary attraction is one of the most important processes in nature, being immediately connected with all the changes and modifications of both living and dead matter. It is the force by which solids and liquids are drawn and held together, which causes plates of glass, wood, metal, &c. to adhere with some force to the surface of water and other liquids, when laid flat upon them. It is by the force of capillary attraction that the waters of the earth are conveyed through its crust in opposition to that of gravity; for water is much lighter than the earthy and rocky strata through which it descends; and has been found at the greatest depths to which miners have penetrated, forming subterraneous streams, which greatly augment after heavy rains. During this transudation of water through the earth, it dissolves and combines chemically with a portion of its mineral ingredients; after which, it is forced

to the surface by hydrostatic pressure, (on meeting with an obstruction to its horizontal progress,) forming innumerable springs and fountains of delicious water.

It is owing to the attraction of liquids for solids that the dust of our roads, which, when dry, has little or no cohesion, becomes so tenacious after rain; or that a rope, when moistened with water, contracts with great force. The combination of tannin with leather, and colouring matter with clothing, are due to a modification of the same power that enables water to combine with salts, or to permeate porous rocks.

Several distinguished philosophers have recently conjectured, that a discovery of the *cause* which determines the rise of liquids through porous solids and capillary tubes, would unfold the latent principle of action in all molecular changes, whether chemical or vital. The trunks, stems, leaves and flowers of all the trees and plants that adorn the earth, are composed throughout of exceedingly small capillary tubes and cells, that attract liquid nourishment from the earth and convert it into their own substance, by the same power which causes the combination of other solids and liquids. And so of all animals. Every muscle, gland, nerve, bone and blood-vessel is composed of imperceptibly small capillary tubes, through which the blood is circulated by the same power which causes universal attraction.

The subject of capillary attraction has been laboriously investigated by many of the most distinguished votaries of science for the last 150 years, but without any attempt to explain the *cause* of the phenomena;

if we except a single suggestion of Newton, contained in his letter to Boyle, concerning the *ether*. He there refers capillarity to the same agent which causes *menstrua to dissolve solids*,—a most important hint, for which his successors have not given him due credit. It must, however, be acknowledged, that he never gave a satisfactory explanation of what causes solution. Still, his views were more just and comprehensive than those of the present day. That he also referred vital attraction to the same cause which produces ordinary capillary attraction, is evident from the following observation: "The same principle which causes a sponge to suck in water, causes the glands in animal bodies to suck in the various juices from the blood, according to their several natures and dispositions." (*Opticks*, page 367.)

In the time of Newton, it was ascertained experimentally by Hawkesbee,—

1. That water rises to the same height in capillary glass tubes of equal diameter, whether the tubes be thin or thick.

2. That it rises to the same height *in vacuo* as in atmospheric air.

3. That the velocity with which water ascends in capillary glass tubes, and its elevation, *cæteris paribus*, is inversely as their diameters.

4. That the upper surface of water, spirit of wine and various other liquids in capillary glass tubes, is concave; which he rightly attributed to a stronger attraction of the particles of water in immediate contact with the glass for it, than to each other.

In 1805, Dr. Young read a paper before the Royal

Society on the cohesion of fluids, in which he reduced all the phenomena to the joint agency of a cohesive and repulsive force, which in fluids, he thought balanced each other. But as he does not explain what causes the particles of liquids to approach or recede from each other, his whole theory is vague and very difficult to comprehend.

The following passage, taken from a paper on capillary attraction, by Professor Sang of Edinburgh, may be regarded as a specimen of the obscure manner in which this interesting subject has been generally treated; and of the prevalent opinion in regard to the recondite nature of the cause which determines the attraction between liquids and solids. He observes, that "the whole of the phenomena are due to a change in the corpuscular arrangement produced by the simple contact of heterogeneous substances, the laws and nature of which change are, and perhaps forever will remain, unknown to us." (*Edinburgh Philosophical Journal*, vol. viii. 253.)

Sir H. Davy maintained, "that water is combined with rocks, earths, salts, wood, muscular fibre, &c. by chemical attraction; but that it combines with glass, porcelain, &c. by cohesive attraction." This is contrary to his own and the general view of chemical attraction, which is defined as "the force that unites different elements and as the antagonist of cohesion," which is supposed to unite homogeneous elements. But there is as much difference between water and glass or porcelain as between water and salts, rocks, wood or muscular fibres.

There is no end to the ambiguities and contradic-

tions that have resulted from regarding cohesion and capillary attraction, as referable to a different cause from that which produces chemical affinity. I have already proved that the particles of water and other compound bodies, are held together by the same agent which causes the cohesion of gold or any other homogeneous body. The same power that unites the atoms of quartz, feldspar and mica and holds them together in the form of granite or gneiss, maintains the cohesion of liquids. This principle has been recognized by Laplace, in a supplement to the 10th Book of the *Mechanique Céleste*, in which he treats of capillary attraction as a modification of chemical affinity.

That this is really the case, would appear from various considerations:—

1. Capillarity is the force by which liquids and solids are made to cohere, whether homogeneous or heterogeneous.

2. Every solution of a solid in a liquid, is the result of a chemical force, by which their particles are united.

3. The force of capillary attraction, by which liquids permeate solids, is always in proportion to their chemical affinity for each other; for example, water has a strong affinity for sugar. It also rises rapidly through it by capillary attraction.

Considering the vast importance of the subject, it is really surprising how imperfect and limited the number of experiments that have been instituted for the purpose of elucidating its nature. Sir David Brewster has given the relative heights to which fifty-two different liquids rose through a capillary glass tube, the

bore of which was 0·0561 of an inch—the general result of which was, that water rose to a greater height than any other liquid. The next in order were muriatic, nitric and nitrous acids; then the volatile oils; after which were alcohol and the ethers; and lastly, sulphuric acid.* But if capillary attraction represent the force by which all liquids and solids cohere, it is obvious, that before we can arrive at any just conclusion, the attraction of innumerable other solids for as many liquids must be ascertained.

As if to show the uncertainty of all experiments, M. Link states, that distilled water, nitric acid, spirit of wine, sulphuric ether, sulphuric acid and the aqueous solution of potassa, (one oz. to six of water,) all rose to the same height between glass plates. What is still more remarkable, he states that the above liquids rose to the same height between plates of copper, of zinc and of copper and zinc soldered together; first, with the zinc surface opposed to the copper; next, the zinc surfaces opposed; and then the copper surfaces opposed.†

Mr. Challis observes, after recounting the above experiments, that "the heights of ascent under similar circumstances, would seem to be alike independent of the liquids and solids."‡ But if this conclusion were

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* Edinburgh Encyclopedia, Article *Capillary Attraction.*

† Transactions of the British Association, vol. iv. p. 293, Report on Capillary Attraction, by the Rev. James Challis.

‡ This error has been amply refuted by the late experiments of Matteucci, who found that when six capillary glass tubes were plunged into as many different liquids, at the temperature of 53·6° F., they rose to the following heights in ten hours, the

well founded, water ought to rise between plates of sulphur, bees-wax, gum lac, resin, spermaceti, tallow, &c. as freely as between plates of glass, which is not the fact. The truth is, that liquids rise most rapidly through such porous solids as are most soluble in them —that is, bodies for which they have a strong chemical affinity. Water rises freely through sugar, salts, ashes and porous rocks, because it has a strong chemical affinity for them. For the same reason, alcohol rises through all such solids by capillary attraction, as are soluble in it; and so of the strong acids. Tallow and water have no tendency to unite chemically when cold. For the same reason, when glass plates are smeared with tallow and brought close together, water will not rise between them, unless they be first wetted. But in this last case, the water rises, owing to its attraction for its own *particles*, for the same reason that they aggregate into spherical drops.

It was observed by Sir John Herschel, that "the discovery of a new law or general fact is scarcely announced when its traces are found everywhere, by which unexpected lights are shed over parts of science

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liquids being of the same specific gravity, viz., 1·075. Solution of carbonate of potassa rose 85 millimètres; sulphate of copper, 75; serum of blood, 70; carbonate of ammonia, 62; distilled water, 60; solution of common salt, 58; milk, 55; white of egg diluted with its own volume of water, 35. He also found, that when glass tubes were filled with pounded glass, alcohol rose 175 millimètres, and water 182; but that when filled with sawdust, the alcohol rose 125 millimètres, and the water only 60. (*Physical Phenomena of Living Beings*, p. 23.)

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that had been abandoned in despair, and given over to hopeless obscurity." (*Discourse on the Study of Nat. Phil.* p. 131.) Nothing could more aptly illustrate this observation than the phenomena of capillary attraction, the *cause* of which, when once pointed out, may be traced everywhere around and within us. But such is the blinding influence of custom, that men disregard what is common and familiar, though it be from analyzing the most ordinary phenomena, that the greatest discoveries have been made, such as that of steam power, the art of printing, railroads, &c.

It was said by Aristotle, that everything is best seen in its smallest proportions. Such is the admirable simplicity with which Infinite Wisdom directs and governs the stupendous frame of nature, that the physical cause of chemical force, and of universal attraction may be recognized in the smallest dew-drop that glitters on the grass.

It has been shown for example, that the atoms of oxygen and hydrogen, are *chemically united* by the agency of caloric, making compound particles of water, which are aggregated into the spherical form by the attraction of *cohesion;* and that it adheres to solid bodies by *capillary attraction*—all of which, according to Newton and Laplace, are modified effects of the same cause that actuates the vast machinery of the universe.

When a certain proportion of caloric is combined with this little dew-drop, it assumes the solid and crystalline form—in another proportion it renders it liquid, and enables it to combine with other bodies—while an additional quantity of the same ether which

held its particles together, separates and expands them into thin air.

Again, the phenomena of a burning candle demonstrate the agency of caloric in chemical and capillary attraction, as effectually as a thousand experiments, though contrived with the greatest skill. By the application of heat to the wick, it is ignited, when it attracts oxygen rapidly from the atmosphere, causing combustion. During this process, the tallow is rendered fluid, and attracted by the burning wick, affording a continual supply of melted matter, which is decomposed, and expanded into flame or dense light.*

Other things being equal, the force and rapidity with which the fluid tallow is drawn up, are in proportion to the amount of caloric given out by the wick. Thus, it would appear that the rationale of *oxidation*, *capillary attraction* and the *generation of light*, are clearly exemplified by a familiar process that has been overlooked by the unreflecting million, and never fully investigated by philosophers. With a view of ascertaining the force of capillary attraction caused by the heat of a burning candle, I performed the following simple experiments:—

About five grains of the heaviest coal ashes were placed around the wick of a burning candle; every particle of which was drawn up in a few minutes, adhering closely to the wick.

I next put about the same quantity of iron filings

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* But if light and flame be identical, and if flame be gaseous matter raised to a white heat, as maintained by Newton, Davy and others, it follows, that the light of combustion is an expanded condition of ponderable matter by caloric.

into the bole of a large candle, all of which were soon drawn up and collected around the wick, as in the former experiment.

There can scarcely be a doubt that filings of silver, lead, gold and even platinum, would present the same results under like circumstances; nor is it a whit more remarkable, than that red-hot iron should attract oxygen, sulphur, mercury and other bodies more strongly than cold iron.

In reply to the above facts, I have been told by grave and learned men, that "fluidity is indispensable to capillary attraction, and that the only agency of caloric in the process is to cause fluidity." But this does not explain why hot water rises far more rapidly through lumps of white sugar, salts, &c. than cold water, nor why those bodies which have the strongest affinity for caloric, attract and absorb water most rapidly, such as the deliquescent salts that are employed in freezing mixtures.

If it be urged that the absorption of water by sugar and salts, is not owing to capillary attraction, but to chemical affinity, I answer, that hot water passes through numerous porous solids and capillary tubes, with a force and velocity proportionate to its temperature. This fact may be verified in the following simple manner. Take two bunches of spun glass about four inches long; insert the end of one into water at 50° F. and the other at 180°, when the latter will be found to rise with greater force and rapidity than the former, in the ratio of at least three to one.

The same is true of amianthus, flaxen thread, bunches of hair, hemp and other textile fibres, when

arranged in a similar manner. But it would be unphilosophical to maintain, that an agent which augments capillary attraction, is different from its primary and efficient cause.

It has been maintained by Laplace, that an increase of temperature diminishes the elevation of liquids in capillary glass tubes; first, by augmenting their capacity; and secondly, by lessening the density of the liquid. He further regards it as a general law, that the elevation of any liquid that completely wets the sides of a capillary tube at different temperatures, is in the direct ratio of its density. This view of the subject has been partially corroborated by the experiments of Sir David Brewster, who found that cold water rose somewhat higher in a capillary glass tube, than when hot—a fact which I also have verified by repeated experiments. Whatever the reason may be of this apparent objection to the views which I have offered, innumerable other facts decisively prove that the rapidity with which liquids pervade porous solids and capillary tubes, is in proportion to the temperature of the liquids, *cæteris paribus.*

When I come to treat of the agency of caloric in the phenomena of life, it will be shown that it is the proximate physical cause of capillary circulation throughout the animal and vegetable world, without which there could be no absorption, secretion, nutrition and growth; that trees and plants are mere aggregations of capillary tubes and pores, through which many hundred million tons of sap are forced up by the power of vital attraction, under the immediate agency of solar heat, and that all the phenomena of

life (which result from an attraction between liquids and solids) are arrested by cold. The principal difference between ordinary capillary attraction, and the capillary circulation of plants and animals, is, that the vessels or tubes of the latter are almost inconceivably small, while the force of all attraction is inversely as the distance; hence the force with which a moistened rope contracts, and raises immense weights; or the force and velocity with which blood and sap are drawn through their minute vessels.

The mutual interchange of two different liquids, separated by a membrane or other porous body, which has been referred by Dutrochet to the operation of a peculiar force, termed by him *endosmose* and *exosmose*, according to their direction, is doubtless a modification of capillary attraction, and of the force which causes all chemical combinations.*

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* Dutrochet's endosmometer consists of a glass tube, with a piece of bladder attached to its lower extremity, expanded into the form of a funnel. On pouring into it an aqueous solution of either gum or sugar, and then immersing the closed extremity in pure water, the latter passes through the membrane into the tube, with a force which raises the liquid within it to a considerable height; while a small portion of the liquid within passes out through the bladder, and mixes with the water, which he calls exosmose. From an immense number of experiments with this instrument, Dutrochet found, that, other things being equal, the force which produces the endosmotic current, is in proportion to the excess of density of the interior liquid over that of the water; that with a solution of sugar, whose density was 1·145, the force of the current was equal to 34 divisions of the scale, but rose to 53 divisions when its density was 1·228; and that syrup, whose density was 1·300, produced a current capable of raising a column of mercury 127 inches in height, which is equal to the pressure of four and a half atmo-

There is another general fact which connects the theory of capillary attraction with that of heat.

Those bodies which have the least attraction for caloric, have the least power of absorbing water, such as furs, silks, woollens, cottons, resins, sulphur, phosphorus and other non-conductors of caloric and electricity. Hence it is that when water is poured on a perfectly dry clean silk dress, it runs off, or collects in large globules, while it is rapidly absorbed by linen, which is a much better conductor of caloric. For the same reason, a lock of wool, cotton, down or fur, will float on water a long time without becoming wet. Or if one end of a perfectly dry skein of silk be suspended in a vessel of cold water, it remains for hours without attracting the water through its fibres; whereas a skein of linen or hemp becomes very soon wetted through-

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spheres, or about 160 feet of water. He also found, that the endosmotic current was generally determined by the liquid which has the greatest affinity for the interposed substance, and by which it is imbibed with the greatest rapidity. In regard to the cause of the current, Matteucci, has, after carefully investigating the subject, arrived at the conclusion, that it is not electricity, (as supposed by Dutrochet and others,) since the latter is not developed by the contact of water with solution of sugar and other liquids. (*Op. cit.* p. 38.) The fact is, that in all such phenomena, there is a transition of caloric from the outer liquid to the interposed membrane, and thence to the interior liquid, just as there is from all liquids to solids during the process of chemical solution, and just as there is in all cases of capillary attraction. I have also shown, that there is a transition of caloric from hydrogen to chlorine during the act of their chemical union to form hydrochloric acid,—as there is from hydrogen to phosphorus, sulphur, &c., during the formation of phosphuretted hydrogen, sulphuretted hydrogen, &c.

out. But if the water be made hot, it rises through the silk also.

In accordance with the above facts, it has been found that mercury and other melted metals, instead of rising through capillary glass tubes, are somewhat depressed, because they have a stronger attraction for their own particles than for those of the glass. That they have also a stronger attraction for caloric, is evident from their greater conducting power. Hence, there can be no transition of caloric from liquid metals to the glass, for the same reason that there is none from cold water to silks, resins, &c., therefore no attraction. But if plates of gold, silver and tin, be inserted into mercury, the latter is attracted by them, rises above its level, and is incorporated with them by virtue of the same power that causes all other attractions between liquids and solids. When mercury is poured on a marble or wooden table, it collects in large globules, for the same reason that water aggregates into large drops when poured upon dry silk, a duck's feathers and other non-conducting bodies; or for the same reason that when plates of glass are smeared with tallow they do not attract water unless previously wetted.

ON THE CONNECTION BETWEEN GRAVITY AND THE MOLECULAR FORCES OF NATURE.

It has been said that the attraction of atoms is not like that of gravitation, inversely as the squares of the distance. This assertion is not only refuted by all analogy, but by the well-established fact that the ele-

vation and force with which liquids rise in capillary tubes, *cæteris paribus*, is inversely as their diameters. The principal difference between the attraction of *atoms* and that of *masses* is, that the former acts at exceedingly small distances, corresponding with the minuteness of atoms; while the power of masses extends to comparatively great distances. The aggregate force of cohesion with which a mass of granite is held together, other things being equal, is proportional to the number of its ultimate particles. The force of gravity with which it presses upon the earth is in the same ratio.

The specific gravity and cohesion of bodies augment in proportion as they are deprived of caloric. The force and rapidity with which they gravitate toward the centre of the earth, when elevated above its surface, augment in a corresponding ratio. We have learned from Sir Isaac Newton that the attractive power of bodies is in proportion to their mass, and inversely as the squares of the distance. The force with which caloric tends to unite with the particles of other matter, and hold them together, is also in proportion to the amount of matter, *cæteris paribus*, and inversely as the squares of the distance. For example, if one pound of water condense two ounces of steam by attracting and absorbing its caloric, two pounds will condense four ounces, and so on. For the same reason, the force with which the caloric of space tends to unite with the matter of the sun, maintains that immense body in the globular form, while it preserves the planets in their orbits around him, being in proportion to his mass, and operating with a power that

varies inversely as the squares of the distance. In like manner, the force with which the caloric of space tends to unite with planets being in proportion to their mass, *cæteris paribus*, must be sufficient to hold them together in the spherical form, and to maintain the satellites in their orbits.

If caloric be the physical cause of cohesion, capillary attraction, and chemical affinity, as I have demonstrated; and if gravitation result from the aggregate action of atoms, as maintained by Newton, Laplace and many other philosophers, the centripetal force of the heavenly bodies must be owing to a modified action of the same cause.*

We are so accustomed to the great powers and movements which mark the course of nature, that we are scarcely aware of their existence until aroused by some extraordinary phenomenon. What can be more obvious and familiar than the power of heat in modifying the surface of our planet? a power absolutely

* According to all the best-established canons of philosophizing, that is the most important principle in physics, to which the greatest number of phenomena may be traced. But if we admit that the accelerated motion of falling bodies, the aggregation of planets, with their annual and diurnal revolutions, are resolvable into the Newtonian law of gravity, it is certain that many other equally important phenomena of nature cannot be referred to the principle of gravitation, such as those of heat, light and electricity, together with the innumerable operations of chemistry, geology and meteorology, all of which are immediately connected with, and may be traced to that law of caloric by which it produces the opposite effects of contraction and expansion, and without which, we cannot explain the most simple modifications of molecular motion.

incommensurable, though for the most part unobserved. Were it possible to compute the aggregate forces of capillary attraction in the circulation of the blood and sap of all the animals and plants that inhabit the earth, we should be amazed at the result. Yet they are all produced by the subtile agency of caloric, a definite amount of which is indispensable to all vital action, from that of the insignificant moss or animalcule, to the most perfect developments of organized existence.

On beholding for the first time so grand a spectacle as the Falls of Niagara, the mind is bewildered by an impression of irresistible power. But if we compare this thundering exhibition of might, with the vast but silent power of solar caloric in evaporation, or of subterraneous caloric in upheaving mountains, the ocean cataract dwindles into a fractional item; for it has been already shown, that a mass of water equal to 415 square miles in area, and one mile in depth, is daily converted into steam, and carried into the atmosphere by the expansive energy of solar heat, and that all the lakes, rivers and springs of the earth are supplied by its precipitation.

We are sometimes aroused to a perception of the wonderful powers that are in nature, by the sudden and awful coruscations of the electric fluid, when darting through the heavens like arrows of Omnipotence, rending rocks, trees and dwellings. But few are aware that it is only a concentrated exhibition of the same agent which causes evaporation, solution, crystallization and vegetation.

It is generally conceded by philosophers, that all

the operations of nature are referable to *attraction* and *repulsion*, which I have proved in the preceding chapters are resolvable into the agency of caloric alone. But if the stupendous forces of chemistry, geology and meteorology, are determined by the agency of solar radiation, why should it not be adequate to produce the annual and diurnal revolutions of planets? That rays of subtile matter, capable of producing heat and light, are continually proceeding from the centre of our system, is self-evident from experience and observation. It would, therefore, be contrary to all analogy, and the indications of common sense, to refer the planetary motions to some unknown hypothetical influence exerted through a vacuum, while there is a *known cause* sufficient to explain the phenomena. Is it not self-evident that if the radiating power of the sun were suspended, they would no longer move around that luminary, and upon their own axis, but desert their orbits, and join the parent orb from which they originally came? It is impossible to conceive how the sun could exert any agency whatever upon the earth, independent of his potent beams. Besides, what can be more simple and natural than the inference, that the same power which aggregates and holds together the particles of planets, guides their movements round the heavens?

It was laid down by Newton himself, as a fundamental axiom, that *no more causes of natural things ought to be admitted, than such as are both true and sufficient to explain the phenomena.* (*Principia*, book iii.)

Lord Brougham also observes in his *Natural Theology:* "Great as our achievements in physical as-

tronomy have been, we are wholly unable to understand why a power pervades the system, acting inversely as the squares of the distance, rather than according to any other law." He adds: "It is inconceivable to our minds how power or any other thing or influence, can act at a distance." (Vol. ii. p. 74.)

When commenting on the Newtonian law of gravity, by which every particle of matter in the universe is supposed to attract every other particle inversely as the squares of the distance, Mr. Whewell asks, "Why do the attractions of masses, or those of their constituent particles, follow this law of the inverse square of the distance?" (*Bridgewater Treatise*, chapter x.) But if it be a fact, that all the separate forces of nature, including those of caloric, are governed by the same law, it is difficult to avoid the conclusion that they are connected together as cause and effect, though we may not yet fully comprehend in what way.

The truth is, that the force of all ethereal emanations is inversely as the squares of the distance, for the obvious reason that they are necessarily diffused in the same ratio. Other things being equal, the repulsive force of caloric in gases and vapours diminishes in the ratio of the distance of their particles from each other. Its heating power decreases in the same proportion, while the attractive and repulsive forces of electricity are known to follow the same law.

Such is the love of mankind for the marvellous, that the most obvious causes of natural phenomena are disregarded, and their explanation sought after by resorting to such as are hypothetical and remote, or obscure. Hence it is, that our books on natural phi-

losophy are filled with speculations about the vacuum of space, while visible and palpable floods of luminous *ether* are continually pouring upon the earth from the great fountain of physical motion and life. When Sir H. Davy observed, that it "was absolutely necessary for the explanation of the planetary motions, to suppose space in the universe void of all matter," he overlooked the existence of solar light, and even of that subtile medium, the vibrations of which are supposed by some to constitute light. That he did so from authority, and without reflection, would appear from what he says in another part of the same work. "It cannot be doubted that there is matter in motion through space between the sun, and stars, and our globe." (*Chem. Phil.* p. 67.)

There is no decisive evidence that any of the ancient philosophers adopted the theory of a perfect vacuum in nature. It was the opinion of Bacon, that the ancient *Pan* "was represented as hairy to denote the rays of things, because everything which acts at a distance may be said to emit rays." (*Wisdom of the Ancients.*)

It was also maintained by Lucretius, who is regarded as the advocate of a vacuum, that *subtile streams* are perpetually flowing from everything, without which bodies could not be discovered at a distance. (*De Naturâ Rerum*, book vi.)

It has been repeated a thousand times, that by reducing the phenomena of gravitation to a general law, Sir I. Newton had revealed the whole mechanism of the universe. But he entertained a far more accurate estimate of what he had done, when he compared him-

self to "a little boy collecting a few choice pebbles and shells on the sea shore; while the great ocean of truth lay all undiscovered before him."

When he resolved the aggregation of planets into the action of their minutest particles, he left his followers in doubt whether gravitation was a *primary agent*, or only an expression of the mode in which some universal cause is observed to operate inversely as the squares of the distance; and whether it resulted from the *pressure* of an all-pervading ether, or from the inherent properties of elementary atoms. (See *Opticks*, p. 351.)

The power of generalization by which he traced remote analogies and reduced a vast multitude of apparently opposite phenomena to the dominion of one law, displayed an admirable faith in the uniformity of nature. Yet the *projectile force*, the *vacuum of space* and the *vis insita* which he represents as the cause of attraction and repulsion, were mere hypotheses, wholly unsupported by evidence. And that the illustrious author himself was fully convinced of this during the latter period of his life, is manifest from the whole tenor of his speculations concerning the ether, which, as I have already shown, he finally regarded as the primary physical cause of cohesion, capillary attraction and of gravitation; but without explaining how it produces the repulsion of atoms and the centrifugal force of the heavenly bodies; or in what way the phenomena of chemistry, geology, meteorology and planetary motion are connected with the influence of the imponderables and the relations of the latter to each other.

But in the total absence of caloric, if such a thing were possible, the whole material universe would disappear no less completely than if annihilated: for it is obvious that in their separate state, the chemical atoms of passive matter could not be recognized by the senses. And I have proved that caloric is the organizing principle by which they are aggregated into visible and tangible forms; consequently, that it is the self-active and universal essence on which all the manifestations of being or existence depend.*

Yet we are told that caloric is not a material sub-

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* And if the particles of all bodies be surrounded by a self-active principle, there can be no such thing as absolute *inertia* in nature.

In opposition to this view of the subject, we are informed by Dr. Arnott that "the greater part of the phenomena of nature may be referred to four elementary truths, viz., *atom*, *attraction*, *repulsion* and *inertia*." He observes, that "*inertia* expresses the fact, that atoms, as regards motion, have a stubbornness about them, which tends always to keep them in their existing state, whatever it may be." (*Elements of Physics*, vol. i. pp. 1 and 2.) In what way atoms have been endowed with this imaginary property has not been explained; nor does Dr. Arnott assign the *cause* of attraction. Until this is done, let no man flatter the world, that even the foundation of physical science has been established on the solid rock of fixed principles.

If it be true that *caloric* is the physical cause of attraction as well as repulsion, and that cohesion and gravity are modifications of the same power, it becomes the business of philosophy to investigate the mode of its operation in maintaining all the molecular and aggregate movements of nature.

The connection of caloric with the phenomena of motion has been virtually recognized by all those philosophers who have regarded heat and motion as identical. But it is obvious that there can be no motion without an agent; consequently, that they have confounded the effect with its cause.

stance, because it is imponderable. It is evident, however, that whatever the cause of gravity may be, it must be without gravity; otherwise we must explain gravity by itself, which would be absurd. The truth is, that when reduced to a state of ultimate diffusion, all matter is imponderable, as in the form of the electric spark, flame, &c. And if caloric were "motion and nothing else," as maintained by Bacon and other philosophers, it would follow that the prime mover in a steam engine and throughout all nature, is motion, —a proposition which involves the glaring absurdity of explaining motion by itself.

But without plunging further into the profound abyss of chaos or practical non-existence that would follow the entire extinction of the organizing principle, it is the legitimate province of science to ascertain how it produces all the phenomena of nature in accordance with the invariable laws of supreme intelligence. Nor is it possible to predict the results which would flow from a searching method of analyzing facts. We often mistake our own inattention and indolence or the mystical inventions of fanciful theorists for impenetrable obscurities, that would vanish before a bold and determined spirit of inquiry. Could the veil be drawn aside which conceals from our inspection the whole mechanism of the universe, nothing, perhaps, would so much excite our astonishment as its simplicity.

From a careful review of the foregoing chapters the following conclusions may be deduced:—

1. That cohesion, chemical affinity and capillary

attraction are modifications of that universal force by which planets and all other bodies are held together:

2. That the particles of all bodies are surrounded by, and intimately combined with, an exceedingly subtile, active and mobile principle, which in certain proportions holds them together, but in larger proportions separates or decomposes them:

3. That the prevalent theory of physics which ascribes the phenomena of attraction to the inherent or immaterial properties of ponderable matter is fallacious and wholly unsupported by evidence:

4. That there is no such thing as a perfect *vacuum* in nature; neither in the pores of bodies nor in those widely extended pores of the universe, termed the planetary spaces:

5. That the *inertia* of matter is a philosophical fiction, because there is nothing quiescent in nature or which possesses the *power of not acting*—neither in the starry heavens nor in the frame of the earth. The sun revolves on his axis, and planets around the sun. The air, the ocean and the solid ground are forever in motion. The molecules of plants and animals are in a state of rapid circulation and change. Yea, the invisible atoms of inorganic matter are in a state of perpetual oscillation and transformation:

6. That the "unknown hypothetical ether of Sir I. Newton is identical with a true physical agent, the properties of which may be ascertained by the various mechanical, chemical and physiological effects it produces; that it determines the aggregation and chemical union of bodies, whether simple or compound, by virtue of its *attraction for ponderable matter;* while it

causes liquefaction, evaporation, explosion, with all the separations and expansions of matter, by virtue of its *idio-repulsive power*:

7. That the same ethereal principle which lights up the universe with radiant glory, directs the planets through their orbits and preserves them in a state of perpetual motion, circulation and renovation:

8. That in the total absence of caloric, if such a thing were possible, the universe would be involved in the darkness, silence and death of primeval chaos:

9. Finally, that caloric is the first of physical causes, or the *essence* which causes things to be what they are.

BOOK III.

CHAPTER I.

ELECTRICITY.

"Nature will not deliver her oracles to the crowd, nor by sound of trumpet. We must open our minds to her in solitude, with the simplicity of children, and look earnestly in her face for a reply."—WALTER SAVAGE LANDOR.

THE grand requisite to a right understanding of nature, is to watch attentively all the changes that mark her progress and the various circumstances by which they are attended. Perhaps there is not a more striking characteristic of the present age than the vast amount of industry and talent that are devoted to the cultivation of separate branches of science, which cannot be understood but as connected parts of one harmonious system. The division of labour, so beneficial to the arts, has not been equally favourable to the progress of enlarged views. Men who devote their attention chiefly to one branch of science, become narrow, technical and incapable of embracing universal truths. The leading object of all science is to reduce a multitude of phenomena to some comprehensive principle or general law, which pervades the

entire constitution of matter. But how is it possible to arrive at universal facts or fundamental laws, without regarding nature as a whole?

The more profoundly we scrutinize her operations the more we discover of simplicity and unity of power amidst all her diversified movements and transformations. Who could have suspected, without a general survey of the widely extended provinces of nature, that the aggregation of liquids into spherical drops and their adhesion to solids are resolvable into the same power that determines the solidity and rotundity of the earth?—which causes rain to descend from on high, rivers to flow toward the sea and planets to revolve around the sun? Yet these various movements were traced by Newton to one and the same law.

What can be more unlike to the mass of mankind than the opposite forces of attraction and repulsion, contraction and expansion? Yet I have proved that they are both produced by one and the same agent; which in certain proportions binds the atoms of passive matter together, as in cohesion and chemical union; while in other proportions it diminishes or destroys their cohesion, as in liquefaction, vapourization, combustion, &c., by which the forms, properties and powers of all bodies are perpetually changed. I have shown that combustion is the disengagement of that principle by which the earth is maintained in its present form; that it is forever flowing from the sun throughout the solar system; and that as it is the spring of all motion and power throughout the earth, it must also be the cause of the annual and diurnal motions of planets.

If, then, caloric be the physical cause of all motion, an universal principle of action in nature, what is electricity? Is it a distinct fluid, *sui generis?* or is it a modification of the igneous principle? These questions, so intimately connected with the whole theory of physics, have never yet been satisfactorily answered. If electricity were the generic moving principle throughout nature, it ought to be everywhere present. But so far is this from being the fact, that it is only under peculiar circumstances that it is developed so as to be appreciable by the senses; whereas, it is impossible to realize the absence of caloric, which is indispensable to all the phenomena of climate, season, the growth of plants and the life of nature. If we admit the existence of an electric fluid, *sui generis*, which darts through conductors and communicates a shock to the living frame, we cannot refer to its agency the melting of winter snows and polar icebergs, the conversion of water into vapour or steam, the elastic force of the atmosphere and other gases, the phenomena of winds, &c., without recognizing its identity with the cause of temperature.

As the subject is acknowledged by all philosophers of the present day to be involved in the utmost obscurity, I shall offer no apology for endeavouring to place it in a new light. While many regard electricity as the cause of all molecular attractions and others as the vital principle, almost everything connected with its origin and laws is either debatable or unintelligible; some maintaining with Franklin, that it is a subtile and inconceivably refined species of matter, diffused throughout nature; others, that it is

a compound of two fluids, each of which repels its own particles and is attracted by the other; while a third party maintains that it is neither, but a mere effect or property of ponderable matter.

Such differences of opinion are alone sufficient to show how vaguely and imperfectly it is understood. Since the time of Franklin, many thousand experiments have been repeated, without affording any precise or satisfactory information in regard to its origin or the mode of its operation in the work of the universe. The discoveries of Galvani, Volta, Davy, Œrsted and Faraday have opened to us an immense store of new facts; but where is the general principle which connects them with the theory of cohesion, capillary attraction, chemical solution, vapourization and the elastic force of gases? What the present state of the science requires, is not the repetition of experiments that have been performed a thousand times, but a more comprehensive and profound investigation of those properties which connect electricity with the laws of heat and light and with the general phenomena of nature.

If ever we shall be enabled to lift the veil which nature has spread over the first principles of things and behold the secret spring of her simple and sublime mechanism, we must first learn the relations of caloric and electricity. If it can be shown, that under all circumstances they are modifications of one and the same agent, the science of nature will be at once divested of that complexity which has hitherto baffled every attempt to reduce the phenomena to fixed principles.

It is not my object to enter into a detailed examination of the various conflicting hypotheses which have been invented to explain the phenomena of electricity; and which, for the most part, have been founded on the partial and often ill-conceived experiments of a little laboratory. The truth is, that all our experiments are but feeble and imperfect imitations of what is perpetually going on in the laboratory of nature. But who has ever studied the natural history of lightning, by tracing its genealogy or nascent production, as connected with evaporation and all the phenomena of precipitation? Who has carefully observed the connection between flashes of lightning and torrents of rain, hail, tornados, hurricanes, &c.? The fundamental laws of electricity which connect it with caloric, light, magnetism or the sublime movements of geology and meteorology, will never be deduced with unerring fidelity from mere artificial experiments. The greater part of those on electricity are calculated rather to amuse and astonish children than to edify those who are in quest of useful knowledge.

It may be proper to observe, before I proceed further, that some of the most enlightened men of the last century supposed that the *phlogiston* of Stahl, (which was the undiscovered latent heat of Dr. Black,) was the basis of heat, light and electricity. Dr. Kirwan, who strangely confounded hydrogen with the phlogiston of Stahl, supposed that electricity might be composed of this substance greatly rarefied, in a state of combination with elementary fire; while M. Benedict De Saussure regarded it as a fluid composed

of heat and some other unknown principle. (*Voyages dans les Alpes*, tome ii. p. 243.) The Abbé Nollet, Dr. Hill, the Rev. W. Jones and some others have maintained that heat and electricity were modifications of the same agent: but as their opinions were not supported by an extended examination of their recondite analogies or fundamental laws, philosophers have continued to regard them as distinct imponderables.

ATMOSPHERIC ELECTRICITY.

The most direct and compendious method of ascertaining the relations of caloric and electricity, would be a careful history of all the phenomena connected with the origin of lightning. If it can be shown that the caloric of aqueous vapour is the basis of lightning, their radical identity must follow as a necessary consequence, notwithstanding the widely different properties which they exhibit. The truth is, that diversity of form and external appearance is no evidence of a difference in the nature and fundamental constitution of things; for it has been demonstrated experimentally by numerous philosophers, that all the varieties of electricity are essentially the same. What can be more different than ice, water and steam? Yet they are composed of the same elements, combined with different proportions of caloric. What more opposite in all their properties than nitric acid and the gases of which it is formed? And so of a thousand other bodies.

It was long imagined that when Franklin drew the lightning from heaven and demonstrated its identity with common electricity, that he had laid the founda-

tion of its true theory. But it is now evident that his views in regard to its origin and nature were partial and erroneous. At one time he supposed that it was generated in the ocean by the friction of salt and water; that oceanic vapour was held in a state of expansion by electricity and heat united, while evaporation from the land was caused by heat alone. He also maintained that the fusion of metals by the electric fluid was a cold fusion; whereas it is now well known that lightning heats, melts, ignites and volatilizes all bodies.

That the general reader may have a distinct idea of the existing state of knowledge in regard to the origin of lightning, it may not be amiss to present the statements of some of the most distinguished recent writers on the subject.

It is observed by Mr. Daniell, that "since the time of Franklin, atmospheric electricity has been almost entirely neglected;" and that on this most important branch of physical science, he had "nothing decisive to offer." (*Meteorological Essays*, p. 135 and 374.) The consequence of which is, that he has left unexplained many of the most striking and important phenomena of meteorology, such as hurricanes, tornados and hail-storms, with all those violent movements of the atmosphere which accompany rapid discharges of lightning. Dr. Arnott also states, that tornados, whirlwinds, &c. are owing to some chemical changes in the atmosphere not fully understood. (*Elements of Physics*, vol. i. p. 397.)

Dr. Thomson observes, in his late work on *Heat and Electricity*, that "the formation of vapour seems to be

connected with electricity, though in what way we have no conception, and that the change of vapour into clouds is probably connected with electrical phenomena not understood." (*Page* 275 and *elsewhere.*) He adds, that "the formation of rain is still involved in impenetrable obscurity."

It is also observed by Professor Forbes, that on the noble science of atmospheric electricity, almost everything has yet to be done. (*Transactions of the British Association*, vol. i. p. 252.)

As the phenomena of lightning have been universally known to be immediately connected with the production of rain, it becomes necessary to ascertain with certainty the cause of evaporation and condensation, before attempting to solve the problem of atmospheric electricity.

That caloric is the true and only cause of evaporation, or the formation of steam, is one of those self-evident propositions which would seem to require no proof. But to remove all doubts upon the subject, the fact has been experimentally demonstrated by Dr. Dalton, to whom the science of chemistry and meteorology is so largely indebted.

He put a little water in a dry glass flask, with a thermometer in it, when he found that a small quantity of vapour was formed at 32° F. At 40° the amount was increased; at 50° it contained still more vapour; while at 60° the quantity was yet further augmented. He also found that when the temperature of the flask was suddenly reduced from 60° to 40°, a portion of vapour was converted into water, and that the quantity retaining the elastic form was

precisely the same as when the temperature was originally at 40°.

The above is a simple and beautiful representation of what is perpetually going on throughout the atmosphere and in the steam engine.

By another series of admirable experiments, he ascertained that the quantity of water evaporated in a given time, was exactly in proportion to the elastic force of vapour at the same temperature, whether formed *in vacuo*, or under the pressure of the atmosphere, with this difference, that in the latter case the process goes on much more slowly, because the atmosphere presents a mechanical impediment to its diffusion somewhat analogous to the obstruction of water by porous sand. From which he inferred that vapour is not chemically united with the air, as had been formerly supposed, but mechanically diffused through it, forming a distinct atmosphere of its own, the elastic force of which is always in proportion to temperature.

At 0° he found the elastic force of vapour equal to the pressure ·064 inch of mercury; that is, about one-fifteenth of an inch. At 32° it amounted to one-fifth of an inch; at 47°, about one-third of an inch, or ·339; at 59°, ·507, or one-half of an inch; at 80°, one inch; and at 90°, 1·360. He also ascertained that the elastic force of vapour at 212°, is equal to the pressure of the whole atmosphere, or 30 inches of mercury.* (*Manchester Memoirs*, vol. v.)

* Dr. Prout observes, that "atmospheric air, under ordinary circumstances, exerts an elastic force equal to the weight of a column of mercury 30 inches high; and that at 212°, aqueous vapour

From the above experiments it follows, that if the temperature of the earth were 80°, from the equator to the poles, the quantity of vapour would be everywhere the same and equal to about one-thirtieth of the average weight of the whole atmosphere; but that if its temperature were reduced from 80° to 59°, one-half of the vapour would be precipitated in the form of rain; if to 32°, four-fifths of it would be converted into snow; and if reduced to 0°, 14 out of 15 parts of the whole would descend to the earth in the form of ice, in obedience to that universal law of nature by which bodies cohere and tend toward a common centre.

But as the temperature of the earth diminishes from the equator to the poles, it is obvious that the amount of water which is capable of existing in the atmosphere in the state of transparent elastic vapour, must vary proportionally in different latitudes. There is also more vapour in the atmosphere of the ocean, other things being equal, than over extensive bodies of dry land.

According to the observations of Captain Sabine and Mr. Caldcleugh, as detailed by Professor Daniell, it would appear, that within the tropical ocean, between the western coast of Africa and the eastern coast of

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obeys precisely the same laws and exerts the same elastic force as atmospheric air under similar circumstances." (*Bridgewater Treatise*, chap. v. section 2.) But it has been shown that the elastic force of atmospheric air is equal to the pressure of more than 1200 atmospheres, (3000 feet of mercury.) It is therefore obvious that Dr. Prout has mistaken the *weight* of the atmosphere for its elastic force.

South America, the point of deposition, or dew-point, is generally about 4° or 5° below the existing temperature; sometimes only 2°; and rarely more than 8°; while in the interior of large continents it is often 20° or 30°, and sometimes 50° or more, below the prevalent temperature. As the atmosphere is in a state of nearly constant circulation, it is removed from one place to another before arriving at the point of saturation, and therefore contains less vapour than it is capable of sustaining at the existing temperature. Within the torrid zone, it is perpetually expanded by solar heat, where it rises into the upper regions, whence it flows to higher latitudes; while it is removed by horizontal currents termed sea breezes, from the ocean to the heated land.

If at the temperature of 80°, the atmosphere contain an amount of vapour equal to the pressure of only half an inch of mercury, while it is capable of sustaining twice that quantity, it will require a reduction of temperature below 59° to cause precipitation. Hence it is, that the atmosphere often undergoes great reductions of temperature without producing rain. But when the air is full of vapour the process of evaporation is arrested; which explains why a cold dry air is more favourable to evaporation than warm air that is already saturated, especially if the former be in a state of rapid motion.

Dr. Dalton found that when boiling water was exposed to a current of air that carried off its vapour as fast as formed, vapourization went on a third faster than in a room where the air was still. Hence it is, that northeast and east winds, which, in the west of

Europe are generally dry, and far below the point of saturation, seldom condense the vapour of France and England; but, on the contrary, often redissolve the clouds already formed, producing clear weather. During summer, when the atmosphere has been for some time comparatively still, it is soon saturated with vapour, which is indicated by heavy dews, and the formation of clouds termed *cumuli*, in which case the weather becomes hot and sultry; because the caloric which is usually carried off by evaporation and winds, accumulates on the surface of the earth and heats the superincumbent air. Such a state of things generally forebodes an approaching thunder-storm.

That the condensation of atmospheric vapour is owing to the abstraction of its caloric by colder currents of air, is evident from the fact, that in the tropical ocean far from land, where the trade-wind blows steadily in one direction, and where the temperature seldom varies more than two or three degrees, there is less rain than in the vicinity of continents and large islands, where currents of air of different temperatures frequently meet.

In the great desert of Sahara, there is scarcely any rain, because the wind blowing over it is generally in the same direction; while the vapour transported by it from the ocean is still further rarefied by the intense heat reflected from the scorching sands, where there are no mountains to arrest its progress. There are also long droughts in Egypt, Palestine, New Holland and many other parts of the world where the winds blow long in one direction, without encountering colder currents. During summer, in the United States, the

atmosphere is often so much heated, that the vapour brought from the ocean by southern winds is not condensed for several weeks, and sometimes two months, but is further expanded, until it becomes saturated, or meets with a current from the northern points of the compass, when thunder-gusts follow.

When I come to treat of winds it will be shown, that the most extensive falls of rain in the middle latitudes are produced by the meeting of immense masses of air from opposite quarters of different temperatures, as during the equinoctial floods and storms. When both contain as much vapour as they can support at their respective temperatures, the amount of precipitation is of course the greatest.

Corresponding with the experiments of Dalton, is the well-established fact, that the greatest quantity of rain falls within the tropics, where the average temperature is from 80° to 85° F., and diminishes on to the regions of lowest mean temperature, where it is about 0°. Hence it is that the largest rivers in the world are found in the tropical regions, as the Amazon, La Plata and Orinoko of South America; and the Indus, the Ganges, the Nile, the Tigris, &c. of the eastern continent.

The following table exhibits a general view of the relative depths of rain in different latitudes:—

	Lat. N.	Inches.
Coast of Malabar	12°	136
Grenada	12°	126
Cape François	19° 46′	120
Senegal	00°	115
Calcutta	22°	81
Havana	23° 19′	109

	Lat. N.	Inches.
New Orleans	29° 58′	63
Cincinnati	39° 06′	36
Philadelphia	39° 57′	36·53
Boston	42° 21′	39·22
Rome	41°	39
England (Dalton's mean)	50°	31
Petersburg	59°	16
Uleaborg	65°	13½

The above results are greatly modified by a variety of circumstances, such as prevalent winds, the relative positions of land and sea, mountain ranges, &c. For example, the trade-wind which blows constantly from east to west over the Atlantic Ocean within the tropics, deposits a far greater amount of rain on the eastern slope of South America, than on its western coast. At Vera Cruz, 278 inches have been observed to fall in the course of one year, and at San Luis, in south latitude, 2° 30′, it has been 280 inches. But in the middle latitudes of the northern hemisphere, where the prevalent wind is from the opposite direction, the case is reversed. Hence the greater amount of rain which falls on the western coasts of Europe and North America, than in the interior of those continents, being wafted from the Atlantic and Pacific oceans. There is also more rain in mountainous regions than on extensive plains. It has been ascertained, that about double the quantity of rain falls on Mount St. Bernard, that falls at Geneva; and that the mean annual amount of twenty places in the lower valleys at the base of the Alps, is 58·5 inches, according to M. Schow. The reason is, that the onward progress of vapour is arrested by mountains, which cause it to

accumulate. Even so far north as Bergen, in Norway, where the southwest winds are impeded by mountains, the annual depth of rain is 88 inches.

There is nothing more admirable in the great drama of nature than the process of evaporation and condensation, by which all the waters of lakes, rivers and fountains are elevated from the ocean; transported over continents and islands; precipitated by polar currents; and distributed in the form of great natural shower-baths over the dry land.

Notwithstanding the greater amount of evaporation and rain in the tropical than higher latitudes, the atmosphere is more transparent, and there are more clear days in the equatorial regions; and more during summer than winter in temperate climates.

According to the estimate of La Cotte, which may be regarded as an approximation to the truth, the average number of rainy days between lat. 12° and 60° N. are in the following ratios:—

N.	Days.
From lat. 12° to 43°	78
43° to 46°	103
46° to 50°	134
50° to 60°	160

It is therefore evident that the transparency of the atmosphere, other things being equal, is in proportion to temperature, which diminishes from the equator to the poles. It is also known to decrease from below upward.* Hence it is that the lower atmosphere is

* It was supposed by Leslie and Dalton, that the diminution of temperature in the atmosphere, on ascending above the earth's surface, was owing to its increased capacity for heat, caused by

transparent, even when the sky is overcast with clouds,* the elevation of which is in proportion to temperature; that is, the plains of condensation are higher within the tropical than middle latitudes; while in the latter their elevations vary with the season. From the observations of Mr. Crosthwaite it would appear that the under surface of dense clouds in the north of England does not exceed 1300 yards during winter, nor 2000 yards in summer. (*Dalton's Meteorological Essays*, p. 136.)

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augmented rarefaction from diminished pressure. But this is not the only cause; for it is well known, that large portions of Asia, Africa and South America are from eight to ten thousand feet above the level of the ocean; whereas their average temperature is much higher than that of isolated mountains of equal elevation in the same latitudes. Mount Lebanon is not much higher than the plateau of Mexico; yet the former is covered with snow nine months in the year, while there is perpetual summer on the table-lands of Mexico, about the same latitude and elevation. The plains of Michigan are about 600 feet above the sea; yet there is no State in the Union in which the temperature rises higher during summer. The truth is, that the greater warmth of the lower atmosphere over extensive plains, than that of mountains, is owing in part to the absorption of the sun's rays by the earth's surface. The stratum of air in contact with the earth becomes heated and rises, when the next stratum is heated and rises, until the whole atmosphere becomes warmed to a considerable height. Hence it is, that the plain of perpetual congelation varies in height in different parts of the world in nearly the same latitudes.

* The dryness of the atmosphere is in proportion to the elevation of its temperature above the dew-point, which decreases from the surface of the earth to the region of clouds. This explains why rain often ceases about mid-day, when the clouds are redissolved by the increasing power of the sun; and why the lower atmosphere is so often obscured in England by a misty rain after sunset during winter.

To pursue this subject through all the complicated phenomena of meteorology, would far exceed the scope of the present inquiry, the principal object of which is to trace the origin and history of atmospheric electricity.

The cardinal facts which connect the phenomena of lightning with the theory of rain may be reduced to the following propositions:—

1. In the torrid zone, where evaporation and rain are most copious, the amount of lightning is greatest. There is also far more during summer than winter in the middle latitudes, and scarcely any in the polar regions.

2. In those parts of the world where there is no rain, there is no lightning, as at Lima in Peru; nor is there any in Egypt, Palestine and other parts of the world during the prevalence of dry weather. It therefore follows,—

3. That where there is no condensation of aqueous vapour, there is no lightning.

The most superficial observers of nature have been impressed with the immediate connection between lightning, intense heat and rapid precipitations of rain. By a careful analysis of the phenomena it becomes self-evident, that *if caloric be the true and only cause of evaporation, condensation and precipitation can be effected only by the evolution of the same agent.* During winter, the quantity and elastic force of vapour in the atmosphere are comparatively low in the middle latitudes, where it is condensed gradually on meeting with colder air. During spring, evaporation augments with increase of temperature, when masses of warm

and cold air often meet, causing frequent showers of rain and sometimes hail, still without much thunder and lightning. But during summer, when the temperature becomes tropical, and the atmosphere saturated with highly elastic vapour, we have tremendous explosions of thunder and lightning, with rapid precipitations of rain and hail. Corresponding with the temperature of the torrid zone, and the amount of evaporation, thunder-storms occur almost daily during the rainy season, on the coasts of India and South America.

One of the most prominent errors in regard to the natural history of lightning, is the prevalent notion that it collects around the surface of clouds, as if they were solid insulated conductors; and that when it becomes accumulated to a certain extent, it darts from one to another. Nothing could be more in opposition to all analogy and experience. Clouds are only banks or strata of moisture, while it is universally known that electricity cannot be accumulated in a moist atmosphere; that it is diffused and dissipated by moisture, and thus prevented from being collected in a Leyden battery. It is accumulated *in transparent aqueous vapour*, (as I shall proceed to show by the most decisive facts,) from which it darts through the neighbouring clouds in such a manner as to present the appearance of proceeding from them; while it is an optical illusion that may be corrected by a philosophical examination; in short, that a large body of transparent elastic vapour from the tropics, may be compared to an immense Leyden battery, filled with an igneous fluid, which is discharged in the concen-

trated form of lightning on approaching mountains, or meeting with currents of cold air.

When the inquiry is divested of all extraneous and hypothetical considerations, it may be reduced to the following conditions.

If it can be shown, that *transparent elastic vapour is the vehicle of atmospheric electricity, and that it is rapidly condensed during discharges of lightning*, it will necessarily follow, that the caloric of such vapour is given out in the concentrated form of electricity during a thunder-storm.

In reply to this reasoning it may be objected, that heavy rains are often unattended with lightning. To which I answer, without fear of contradiction, that *the formation of clouds and precipitation of rain are far more rapid during thunder-storms than when there is no lightning*. It is stated by Humboldt and others, that within the tropics during the rainy season, the first indication of an approaching storm is generally a light wind, with a few scudding clouds; but that when it begins to lighten, the whole sky is suddenly obscured by dense clouds that immediately descend in torrents of rain.

That atmospheric electricity is a constituent of aqueous vapour, will appear from the description of a thunder-storm among the Alps, as recorded by the celebrated De Luc, in his "*Idées sur la Meteorologie.*" He states that *it commenced with abundant discharges of electricity from dry transparent air, which contained neither vapours nor the electric fluid, but the constituents of both,—and that clouds were suddenly formed around the summit of the Buet, during each explosion.* In other

words, that simultaneous with the discharges of lightning from dry transparent air, was the sudden formation of clouds, and precipitation of rain.

From another portion of De Luc's work, it is obvious that he mistook transparent aqueous vapour for "dry air." He supposed that clouds were formed by the union of oxygen and hydrogen gases by the agency of electricity, as water is generated by passing an electric spark through them.*

It was long ago supposed by Plato, that fire, when concreted, becomes air, which, on being further condensed, constitutes clouds and water; which are also convertible into earthy bodies; and all of them again into flame or fire. (See *Timæus*, ch. xxxi.)

According to Seneca, the ancient Stoics taught a similar doctrine—"that air was converted into fire and water," during a thunder-storm:—(*Natural Questions*, book ii.) from which it would appear, that they were ignorant of the process of evaporation, by which water is expanded into elastic vapour like air; or that they confounded the one with the other.

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* This hypothesis has been revived by Mr. Murphy of Cambridge, in a recent work on Electricity, the professed object of which is to reduce the science to mathematical laws. Had this author traced the history of rain from the first process of evaporation, he would probably not have maintained that heavy showers of rain which accompany lightning, may be produced from the combination of oxygen and hydrogen by electricity, after it had been demonstrated by Dalton that vapour or steam is composed of water and caloric, and that its condensation is owing to the evolution of caloric, whether attended with lightning or not. The supposition of Dr. Darwin was more consistent, who maintained that electricity was the cause of evaporation, because discharges of lightning are attended with rapid precipitations of rain.

philosophizing, to maintain that water is converted into vapour by one agent, and again reduced to water without the evolution of the same agent. No sophistry can evade this simple but rigorous logic. That the rapid precipitation of rain during a thunder-storm is in proportion to the amount of lightning, is attested by all experience and observation. Hence it is, that during the fiery tempests of the tropical regions, termed hurricanes, more rain is precipitated in a few hours, than during as many months in colder latitudes.

It may be said that lightning is sometimes unattended with rain: to which I answer, that vivid flashes never occur immediately over head, without a precipitation of rain or hail. This is the most convincing proof, that the caloric of vapour is given out in the condensed form of lightning, and is that kind of evidence from which there is no appeal, being the spontaneous declaration of nature herself, made in the most sublime and ostensible manner.

On the 2d of June, 1833, the author had an opportunity of observing for himself, that *lightning proceeds from transparent vapour, and not from clouds already formed*, as many persons suppose. This beautiful display, which was witnessed by hundreds of individuals with admiration, occurred at New York, about 7 P.M., after a showery day. The wind was from the south, while the western sky was of a brassy hue, through which the descending sun was perfectly visible. In this state of the atmosphere, a vivid streak of lightning was seen to dart from it, when clouds were immediately formed that intercepted the solar rays, as if an immense black curtain had been drawn across the

western sky, and attended with copious precipitation of rain.*

Such facts afford more decisive information in regard to the nature of lightning, than volumes of mere speculation, or than thousands of artificial experi-

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* Since the London edition of this work was published, I have met with many similar statements in the newspapers of the United States, and in the writings of the older meteorologists of Europe. It was maintained by Franklin, Saussure and others, that thunder never proceeds from a solitary cloud. But, in opposition to this opinion, it is related by M. Marcorelle of Toulouse, that on the 12th of September, 1747, the sky being generally clear, a single small cloud was observed, from which lightning and thunder proceeded, by which a female named Bordenare was killed. Duhamel also relates, that on the [illegible] of July, 1764, at half-past five P. M., in bright sunshine and a clear sky, there appeared a small dark [illegible] cloud, from which lightning and thunder proceeded, by which the steeple of Dammartin-villiers was stricken. [illegible] the French corvette Urania, farther relates, that [illegible] in [illegible] 1818, he saw a small [illegible] the magnitude of the sun, from [illegible] followed by thunder which [illegible] mischief. It is also stated [illegible] that on Monday, the 28th [illegible] Worcester, in Massachusetts, a building was [illegible] by lightning which proceeded from a small cloud and was [illegible] by any rain. But it is here worthy of notice, that in [illegible] where the lightning is at a considerable distance, there may be rain at that place, though not perceived by an observer. Several of the above examples are related by Dr. Lardner, who has not, however, perceived their bearing in regard to the identity of caloric and atmospheric electricity. The immediate connection of rain with discharges of electricity from aqueous vapour, seems to have been noticed in the Book of Job: "Who hath divided a way for the lightning of thunder, to cause it to rain on the earth?" (Chapter xxxviii. v. 25.)

ments; for they completely establish the important fact that elastic vapour is the proximate source of atmospheric electricity, and not clouds. Nevertheless, I shall prove by the experiments of De Saussure, Read and Pouillet, that electricity may be disengaged from all vapours generated by the agency of caloric, whether by natural or artificial means, or by combustion; that it rises from the earth in a latent state of combination with aqueous vapour, which it maintains in the elastic form,—whence it may be withdrawn by conductors, and tested by the electrometer.

Scarcely one of the older writers on meteorology, clearly understood the simple process of evaporation. Beccaria supposed that the earth was full of electric matter, which rises to the upper regions of the atmosphere, carrying with it water in the form of vapour. (*Priestley's Hist. of Electr.* p. 340.)

Franklin also supposed, that vapour was elevated from the sea, by the united agency of heat and electricity. But it is now well established, that caloric is the vapourizing agent all over the world; that wherever there is heat, with water in sufficient quantity, vapour is produced, whether from the ocean, fresh water lakes and rivers, or from the surface of the dry land; and that, other things being equal, its amount, like that of lightning, is determined by temperature. Had Franklin clearly understood the process of evaporation, and traced the connection between discharges of lightning and precipitation, he would probably have added to his discovery of the identity of lightning and common electricity, the still more important fact, that caloric

and electricity are different manifestations of the same potent element.

The celebrated Volta adopted the opinion of Franklin, with some slight variation. He supposed that all bodies contained electricity, a portion of which was evolved whenever they underwent a change of state; that when water was converted into vapour by the agency of solar heat, it acquired a greater capacity for electricity, which it absorbed and carried into the atmosphere during the process of evaporation; that it was liberated whenever the vapour was condensed by cold, and thus accumulated in the upper regions of the air;* that when clouds are formed, which are good conductors of electricity, they become a medium by which it is conveyed back to the earth in a tranquil manner, or in the form of lightning, according as it is more or less abundant. (*Journal de Physique*, Août. 1783.)

Some experiments of Lavoisier and Laplace, pub-

* Seneca informs us that Anaxagoras taught that lightning descended from the ethereal regions, and was collected in clouds, from which it was discharged after being greatly accumulated. The same hypothesis has been recently brought forward as new by Dr. Hare, with this difference, that he supposes the earth to constitute another great reservoir of the electric fluid, and that the atmosphere is situated between two oceans of electricity; while the clouds formed in the non-conducting air operate as movable insulated conductors. He further supposes, that thunder-storms are more frequent during warm than cold weather, in consequence of the greater elevation to which the clouds then attain, and their consequent approximation to the celestial ocean of electricity. (*Theoretical Suggestions Respecting the Causes of the Tornado, or Water-spout*, &c., by Robert Hare, M.D., of Philadelphia.)

lished in the Memoirs of the French Academy in 1781, were intended to prove that electricity is disengaged during the process of evaporation: but their results were vitiated by the agency of chemical action, which accompanied the process of evaporation in most of their experiments. Besides, they did not extend their researches to the connection of atmospheric electricity with the phenomena of meteorology; they have therefore been very little attended to by philosophers.

Lavoisier and Laplace found, that when water was poured by drops into an iron vessel heated, while the vessel communicated with an electroscope, it gave signs of positive electricity; that when dilute sulphuric or nitric acid was poured upon iron filings, electricity was evolved; also, during the action of dilute sulphuric acid on chalk and during the combustion of charcoal. Their experiments tend to show the relation between chemical action and the evolution of electricity, but throw very little light on the connection of electricity with evaporation.

The most decisive results are those of De Saussure and Mr. Read, who performed many hundred experiments with the greatest care, for the purpose of ascertaining the source of atmospheric electricity; the result of which led them to the conclusion, that a perpetual circulation of the electric fluid is kept up by means of evaporation and condensation.

De Saussure found that when water, spirit of wine and ether were made to boil in silver, or white porcelain vessels heated, and suspended by silk cords, negative electricity was obtained; but when a piece of red-

hot iron was thrown into a vessel containing a small quantity of water, positive electricity was strongly developed. He supposed that the vast quantities of electricity discharged from volcanos was generated by the action of so great a heat on waters that find their way to those immense furnaces. In all such cases, it is disengaged partly by chemical action, as will be noticed when I come to treat of voltaic electricity and volcanic forces.

The following experiments of De Saussure show that aqueous vapour, however produced, contains electricity. He caused water to boil in a coffee-pot by placing it on an insulated chauffer, (heater,) when the coffee-pot was electrified negatively, during the condensation of the vapour. He varied the experiment, by causing the vapour of boiling water to pass into the cap of an insulated alembic, to which he applied snow, causing a condensation of the vapour contained within it, when the apparatus became electrified negatively. The same effect was produced in a more remarkable manner, by applying a mixture of common salt and snow as a refrigerant. He observes, that *in all such cases, electricity is disengaged from the vapour and conducted to the metallic vessel during the process of condensation.*. (*Voyages dans les Alpes,* tome ii. p. 251.)

De Saussure adds, that *the electric fluid is generated during the conversion of water into vapour by heat; that it combines with vapour and contributes to its formation;* "that it rises invisible and inactive, hid in the bosom of vapours; but afterwards displaying its energy when those vapours are changed in form, it redescends ac-

tive, animated by its penetrating and expansive force." (*Voyages dans les Alpes*, tome ii. p. 244.) But it is quite evident that his ideas were vague and unsettled in regard to the origin of atmospheric electricity; for he observes in another volume of the same work, that it seemed to be produced by the friction of clouds against the air; by the action of the solar rays; or by these two causes united. (Vol. i. p. 241.)

Dr. Thomson has expressed nearly the same opinion in his late work on *Heat and Electricity:* "that atmospheric electricity may result from the friction of two currents of dry air moving different ways." (*Page* 441.)

De Saussure supposed that there were two kinds of vapour; the one vesicular* and visible, which contained electricity; while transparent elastic vapour was combined with, and sustained by, the expansive agency of heat alone. (Vol. ii. p. 259.)

But I have shown, from the observations of De Luc on the Alps and from my own at New York, that lightning is disengaged rapidly from transparent vapour, by which the latter is condensed into rain. The observations and experiments of De Saussure are highly

* The vesicular theory originated with Derham, who supposed that vapour was composed of hollow sphericles of water filled with *highly attenuated air*, which Mr. Leslie terms a "fanciful notion, countenanced by certain dubious optical appearances." Saussure says, that while travelling in the Alps he was enveloped in a *mist* which was almost stagnant, when he was astonished to see drops, as he thought them, floating slowly past him, without falling to the ground, some of them larger than the largest peas; but catching them in his hand, he found them to be bladders, inconceivably thin. Truly, the philosopher must have been in a *mist.* But how was Berzelius trapped into the same illusion?

valuable; while his theoretical views are often inconsistent. He supposed that electricity was *destroyed by explosions of thunder;* that is to say, it is generated by evaporation and destroyed by condensation. But I have already shown, that such phenomena result from changes of state; and it will be seen hereafter, that there are no assignable limits to the metamorphoses of this subtile agent. They are as diversified as the multitudinous forms of external nature. Though invisible *per se*, it is everywhere busy in all the transmutations of matter. The fabled Proteus of old is but a feeble representation of the rapid changes through which it passes—now silently bearing the waters of the ocean aloft in the atmosphere in a state of transparent ethereal vapour—now darting in vivid coruscations from its aërial palaces on high—leaping upon the mountains and cleaving rocks asunder—resounding through the heavens with its great music, and sprinkling the earth with genial showers of fruitful rain. Though constantly changing, it is never destroyed, but is always the same powerful agent by which Infinite Wisdom directs and governs the universe. Who can refrain from sentiments of profound admiration of its godlike energy and the wonderful manner in which it produces an endless succession of the most diversified effects?

There is not a more striking evidence of beneficent design in the whole mechanism of creation, than the rapid evolution of *heat* from atmospheric vapour, in the concentrated form of lightning, during hot and sultry weather. Were it evolved gradually, as during winter, the number of rainy days would be so far in-

creased, as greatly to interfere with the operations of agriculture. On the other hand, being given out in the diffused form of sensible heat during the formation of clouds, rain and snow in the higher latitudes, it moderates the excessive cold which would otherwise prevail during winter.

It was finely observed by a distinguished writer of the present day, "that the delight with which speculative minds contemplate universal truths, does not so much spring from perceiving that some general principle holds good and reappears in a great number of instances very nearly, or perfectly resembling one another, as from discovering the occult presence or efficacy of some such principle in a multiplicity of cases which have few points, or perhaps no other point of resemblance besides this one of their obedience to some abstract law." (ISAAC TAYLOR, *Saturday Evening*, p. 131.)

When men shall thoroughly comprehend the agency of caloric in all the diversified forms of electricity, and how they are resolvable into one general principle, innumerable new truths, the existence of which has not been suspected, will gradually open to view, until the vast and complicated mechanism of nature shall be fully unfolded and reduced to an intelligible theory.

I cannot dismiss this subject without noticing the recent experiments of M. Pouillet, in connection with those of Mr. Read, which were performed fifty years ago; because their conclusions are in direct opposition to each other. Mr. Read maintained that electricity is given out by aqueous vapour, (the constituents of which are oxygen, hydrogen and caloric,) and by the

vapours that are exhaled from burning substances;* while M. Pouillet contends that electricity is never developed by evaporation, unless attended with *chemical action.*

It was before stated, that De Saussure obtained electricity during the evaporation of water from silver and porcelain vessels, where no chemical action can be supposed to have existed. Mr. Read insulated a large hollow tin cone, with many yards of small wire coiled up within it, one end of which extended from the apex of the cone, which was open, and was connected with a sensitive electrometer. Under this cone was placed a vessel of water, the vapour from which, on rising, was condensed and collected by the cone and wire, when *positive electricity* was produced, (which De Saussure could not obtain without chemical action.) The same result was obtained by burning different substances under the cone. He maintained that the electricity which he derived from the atmosphere in different degrees, at all seasons and times of the day, was elicited from its vapour. He observed that during the formation of thick fogs electricity was abundant, but scarce during their solution and dispersion. (*Spontaneous Electricity*, p. 15.) He also found that his lightning-rod was less charged with electricity while immediately under a cloud, than when at some distance from it; and that it acquired more electricity before the rain commenced than afterwards; a fact which was also observed by Beccaria.

* Mr. Read considered combustion as a species of evaporation, by which solid and fluid bodies were converted more or less rapidly into the gaseous state.

These beautiful and important experiments will enable us to comprehend those of M. Pouillet, which he seems not to have rightly understood himself. He placed a cylindrical piece of charcoal in a vertical position, the top of which was two and a half or three inches below a plate of brass that was connected with the condenser. When the upper part of the charcoal was ignited, a current of carbonic acid arose and came in contact with the brass plate, by which the condenser was positively electrified in a few minutes. By placing the inferior end of the charcoal on the condenser and igniting the upper end, the condenser was charged with negative electricity. From these experiments Pouillet concluded, that during the combination of oxygen with carbon, it gave out positive electricity, while the carbon gave out negative electricity.

During some of his experiments, both positive and negative electricity were evolved by the combustion of charcoal and hydrogen; from which it would seem to follow, that positive and negative electricity are only *plus* and *minus* conditions of the same agent; although this seems not to have been suspected by Pouillet. The following experiments are among the most instructive which have been recorded by the French philosopher. He caused hydrogen gas to flow out of a glass tube. When it was ignited, a vertical flame was produced, nearly half an inch in breadth and three inches in height. A coil of platinum wire was employed to conduct the electricity from the flame to the condenser. When the coil was large enough to inclose the flame, and to be about four inches from its external surface, positive electricity was indicated, as

in the experiments of Mr. Read, which became more and more intense as the distance diminished, until the coil touched the flame, when nearly all signs of electricity disappeared. Hence it was concluded, that around the flame of hydrogen gas there is *a sort* of atmosphere at least four inches in thickness, which is always charged with positive electricity.

Now, it is obvious that aqueous vapour is produced during the combustion of hydrogen gas, constituting an atmosphere above and around the flame; which vapour gives out positive electricity as proved by Mr. Read. It is also evident, that in the immediate vicinity of the flame, the vapour cannot be condensed by the platinum coil; and therefore cannot give out much, if any, electricity. It is for the same reason, that the vapour of the atmosphere gives out less electricity during the heat of a clear day, than in the evening. When Pouillet placed a small coil of platinum wire in the centre of the flame, so that it was enveloped on all sides, and made to communicate with a condenser, the instrument was electrified negatively. This is a thermo-electric phenomenon which has very little connection with atmospheric electricity, as will be seen hereafter. He found that during the combustion of alcohol, ether, wax, oils, fat and many vegetable bodies, the same phenomena were exhibited as in the experiments with burning hydrogen. (*An. de Chim. et de Phys.* xxxv. 401, et xxxvi. 5.)

The principal error of M. Pouillet was in supposing that electricity is never produced by evaporation, unless attended with more or less chemical action; that when water was evaporated from platinum cups, no

electricity was evolved. In addition to the evidence of De Saussure, are the recent experiments of Mr. Harris, who has found that the evaporation of pure water from platinum vessels is attended with a distinct evolution of electricity; so that the doctrine of Pouillet cannot be admitted, that atmospheric electricity is wholly supplied by chemical action and the growth of plants. It is impossible to conceive that the vast amount of lightning disengaged from aqueous vapour, could be generated by chemical action, which is far more energetic upon the dry land than in the ocean, from which the vapour is obtained: nor can it be maintained that the process by which water is separated from the ocean brine is chemical; for I have shown that it is a mechanical force, which is proportional to temperature. (See chap. iii. book i. and the subsequent examination of the two electric fluids.)

From the brief history thus presented of atmospheric electricity, it must be obvious to the intelligent reader, that the knowledge hitherto derived from experimental researches, has been extremely vague and imperfect, and that its relations to the caloric of evaporation have scarcely been inquired into. On the other hand, it is equally evident, that if we analyze the phenomena of evaporation and condensation, as they are constantly going on before all eyes, we obtain a simple and satisfactory solution of the problem. The fact which was announced by Dalton, *that caloric is the only cause of evaporation*, taken in connection with another fact, *that aqueous vapour is condensed into rain or hail, with a rapidity proportional to the amount of*

lightning, are decisive in regard to the convertibility of caloric into electricity.

The ideas of the ancient Greek philosophers, which were derived from observation without experiments, were more in accordance with nature and reason than the hypotheses of modern times. It was maintained by Lucretius, who gives the doctrines of Epicurus, that lightning consisted of fire alone, and that it was derived from the sun. He represents the igneous particles as rushing to a focus, by which concentration they acquire the power of instantaneously fusing metals.* (*De Naturâ Rerum*, lib. vi. 108.) That this subtile agent is greatly concentrated on quitting a mass of vapour in the form of lightning, is proved by the fact, that a single spark or flash, causes a precipitation of rain over several thousand acres; and that it is a material agent, is demonstrated by its mechanical force in rending rocks, buildings, ships, trees, &c.

* He further states, that it is by the meeting of warm and cold air that they are elicited. It is not very obvious *how* this subtile matter becomes concentrated into a ball of fire on quitting a mass of vapour; but such is the fact. It is equally difficult to explain how the electricity of a Leyden battery is condensed on presenting a metallic knob. Perhaps it is owing to all its particles being attracted to the centre of the knob; or that the igneous matter of vapour is attracted to the centre of whatever object excites it. It is worthy of notice, that when a metallic *point* is presented to the knob of a Leyden bottle charged with electricity, the igneous fluid is drawn off gradually, and no visible spark is produced: but when a larger mass of matter is presented, as a knob of brass, or the knuckle, it is all withdrawn at once. Thus mountains, clouds, buildings, &c. attract a large portion of the electric fluid at the same moment, producing a concentrated spark many hundred thousand times larger than one from a Leyden jar.

as effectually as if it were a ball of iron discharged from a cannon.

Lord Bacon supposed that the greatest heat in nature was that of lightning, from its instantaneous power of fusing metals, and of igniting other combustibles. As an additional proof that it is a concentrated exhibition of the igneous principle, it may be observed, that when solar caloric is greatly concentrated by a large burning-glass, it fuses, ignites and volatilizes the hardest gems in a few moments, thus approximating the character of lightning. But since the time of Bacon, philosophers have discovered that electricity can produce all the above effects without being a material fluid; others, that it proceeds from the earth to the clouds, and not from atmospheric vapour to the earth; while others again resolve all its mechanical and heating properties into undulations of the "unknown ether."

If any additional evidence were required to establish the proposition that the caloric of aqueous vapour is convertible into electricity, it is afforded by the recent discovery that the electric spark may be obtained from steam as it issues from the boiler of what is called the hydro-electric machine. This discovery was made in 1840, by a man who was intrusted with the care of a steam engine at Seghill, near Newcastle, in England. Having accidentally immersed one of his hands in the steam that issued from a crack in the cement by which the safety-valve was secured to the boiler, while the other was applied to the lever of the valve for the purpose of adjusting the weight, he was surprised by the appearance of a brilliant spark between the lever

and his hand, accompanied by a violent wrench in his arms. The man further observed that the same effect was produced whenever he attempted to touch any part of the boiler or iron-work connected with it, provided one hand was exposed to the steam; and that he also communicated a shock to every person whom he touched with the other.

These facts led Mr. H. G. Armstrong to the construction of what he calls the hydro-electric machine. It consists of a cylindrical boiler, (insulated by glass legs,) to which a number of metallic tubes are connected, for the purpose of conveying off a large quantity of steam, which is made to issue from a single opening. When the steam was let into the tubes, sparks about fifteen inches long were observed to pass between the opening from which it issued and the prime conductor, affording a miniature display of lightning and thunder. In a paper on the subject, which has been greatly overrated, the celebrated Faraday maintains that the electricity is not developed by evaporation, nor by the condensation of steam, *but is wholly the result of friction;* that steam is merely the mechanical agent by which the particles of water are made to rub against the sides of the tubes; and that the phenomena are in no way connected with atmospheric electricity. (*Exper. Researches*, ser. xviii. pp. 20, 21.)

Yet Mr. Faraday relates in this very paper experiments which demonstrate in the most decisive manner, that electricity is developed during the condensation of steam, in the same way that lightning is evolved from atmospheric vapour, during its condensation into

rain, on meeting with a wave of cold air. For he found that whenever the tubes through which the steam issued from the boiler were made hot before the steam was let on, no electrical phenomena were produced; *but that if while the steam was issuing, the pipes were cooled by a jet of water, electricity was evolved.* Like Armstrong, he also found that the electricity thus obtained was always positive, while the sparks obtained from the boiler were negative. Will it be credited, that after all these results, Faraday attributes the electricity of steam to friction, and not to the condensation of steam? and that his opinion is adopted by all professed electricians in England?

M. Peltier also found by experiment, that the electricity is evolved neither before nor after the steam is projected, *but only at the instant of its condensation into aqueous vapour;* in other words, that so long as the steam remained in the elastic state, there were no signs of electricity; but that whenever it was condensed into watery vapour, there was a disengagement of the electric fluid. He further ascertained that the quantity and intensity of the electricity evolved were in proportion to the temperature and elasticity of the steam. He adds, that with a small Papin's digester, the amount of electricity obtained was in proportion to the quantity of steam that escaped, its tension remaining the same. M. Peltier also found, that by elevating an electrometer, terminated by a polished copper ball, under the column of vapour given off by the boiler of a locomotive engine, electrical phenomena were produced; being more considerable in proportion to the velocity of the engine, and the rapidity with

which the steam was condensed. (*Electrical Magazine*, Oct. 1844, pp. 450–7.) The most notable fact connected with this part of the subject is, that M. Peltier was not led by his own beautiful experiments to the simple and natural conclusion, that *the caloric which converts water into vapour or steam, is given out in the form of electricity during the process of condensation.*

CHAPTER II.

THEORY OF WINDS.

Of all the subdivisions of general philosophy, there is none so little entitled to the name of science as meteorology.—MASON GOOD.

THAT the reader may comprehend more fully the connection between caloric, evaporation and atmospheric electricity, it becomes necessary to present a cursory view of atmospheric currents generally.

The unequal distribution of solar caloric over the earth's surface, together with its annual and diurnal revolutions, determine the periodical movements of the atmosphere which surrounds it.

It has been long known, that there are three great currents of the aërial ocean, by which it is kept in a state of perpetual circulation: one from the polar regions toward the equator, which is an under current; another from the equator to the poles, which is an upper current; and a third, called the great tropical current, or trade-wind, which blows from east to west around the globe for about 30° on each side of the equator; thus sweeping over a breadth of 3000 miles.

There is another general wind, which blows from west to east in the middle and higher latitudes, about two-thirds of the year in the northern hemisphere;

while in the middle latitudes of the southern hemisphere, where there is little or no land, it is said to be nearly as uniform as the trade-wind. Dr. Hadley, and after him Dr. Franklin, attributed these general currents to the following causes. "The air between the tropics, being constantly heated and rarefied by the vertical sun, rises, when its place is supplied by air from the higher and polar latitudes, which, coming from parts that had less diurnal motion, and not suddenly acquiring the swifter motion of the equatorial regions, becomes an east wind; the earth moving from west to east, and slipping under the air." (See *Franklin's Works*, vol. iii. p. 236.)

These general views have been greatly extended by Dr. Dalton and Mr. Daniell. The first of these philosophers observes, that the diurnal motion of the earth at the equator is 1040 miles per hour, and diminishes gradually on to the poles, where it is nothing. (*Meteorological Essays*, page 88.) And Mr. Daniell has demonstrated in the most conclusive manner, that from the greater density of the polar atmosphere than the equatorial, its height is proportionably less; so that the expanded air between the tropics must rise and flow toward the poles as an upper current. Before rising, it has acquired the tropical motion of the earth from west to east, which it retains, until descending in higher latitudes, where the earth's diurnal motion is less, it mixes with the lower air, and gives it a westerly direction.

The force and direction of the trade-winds are influenced by the proximity of islands and continents. Along the western side of Africa, their direction is

reversed. To the distance seaward of about 300 miles, they blow toward the heated land: they are reversed in a similar manner in the Pacific, west of South America. When the sun is in the northern tropic, they extend several degrees farther north than during our winter; and when the sun is south of the equator, they prevail farther south.

There is, near the equator, in the Atlantic and Pacific oceans, a belt that separates the trade-winds, where the great polar currents from the north and south meet and neutralize each other, and the regular course of which is arrested by a tendency of the atmosphere to flow toward the heated coasts of Africa and South America. The regions within this tract are characterized by a constant succession of irregular winds and calms, with storms of thunder, lightning and rain: they are termed by seamen the swamps or horse latitudes, and are extremely sultry, owing to the motionless state of the atmosphere, caused by opposite forces that neutralize each other.

During winter, in the northern hemisphere, the polar latitudes being deprived of the sun's rays, while the tropical parallels are heated, we have a predominance of northerly winds, the dense polar air pressing toward the tropics, to restore the equilibrium; while the greater velocity of the middle and tropical than of the northern latitudes, causes a deflection of the polar currents to the southwest and west, making northeast and east winds, which almost uniformly succeed to north winds, and continue blowing until an equilibrium is established between the higher and middle latitudes. In the mean time, under the influ-

ence of the solar beams, the land soon becomes more heated than the ocean, even south of it, which causes a south wind until the equilibrium is restored between the sea and land atmosphere.

During summer, in the United States, southwestern winds predominate, and northern winds during winter. The same thing is true of India, China and Arabia. They are heated during summer, and the atmosphere over them is rarefied, which causes the air to flow in upon them from the tropical seas, when it is deflected to the east, by passing from latitudes that move rapidly, to those which move more slowly. This is what seamen term the southwest monsoon.

When the sun is south of the equator, the air moves from the northern land, which is cooled down, toward the equator, that has a swifter motion, thus causing the northeast monsoon, which corresponds with the northeast wind of the North American cold season. It was supposed by Volney that the prevailing southwest wind of the Mississippi valley was a recoil of the tropical trade-wind, deflected by the Andes of Mexico; but the fact which he states, of its crossing the Alleghany Mountains, and advancing northeastward, as far as Montreal and Quebec, is sufficient to prove that it must be owing to a cause far more extensive and general in its operation than mountain ranges.

During summer in North America, the land is greatly heated, and the air presses from the Atlantic ocean, especially during the day, causing a sea breeze; when from the south, it is changed into a southwest wind, by passing from latitudes that revolve at the rate of eight or nine hundred miles per hour, to those

which move only six or seven hundred miles per hour.* The southwest and northeast are the prevalent winds in the United States and the west of Europe. In Great Britain they blow about 300 days in the year.

It has been observed in the United States of America, that regular winds generally follow the sun, exhibiting a tolerably uniform succession of circuits from left to right, and blowing from all points of the compass within a few days. For example, the ordinary succession of winds is, first, from the north; next, from the northeast, then from the east; southeast; south; southwest; west; northwest, and so on, in pretty regular succession, and rarely, if ever, performing an entire circuit in the opposite direction. As the greater portion of the United States is more heated by the sun than the ocean, even south of them, (because the surface is stationary,) and for a longer time, the wind blows from the southwest a greater number of days than from any other quarter. At the same time, it is worthy of notice, that during extremely cold winters, the wind has continued from a month to six weeks from the northern points of the compass.†

* It is the meeting of this wind, charged with aqueous vapour from the ocean, with the colder northerly currents, which causes vast precipitations of rain in the United States, during the latter part of summer and beginning of autumn, attended with the most fearful displays of thunder and lightning, when extensive hurricanes prevail in the West Indies, the Gulf of Mexico and the southern portions of the Union.

† According to observations made at sixteen different military posts in the United States, from lat. 35° to the northern extremity of the Republic, including those of Sir Edward Parry, in the polar regions, winds prevail from the southwest, west and north-

In addition to the above winds, opposite currents frequently meet in the higher atmosphere, *which are not observed at the earth's surface, and thus cause precipitations of rain.* A striking proof of this was witnessed on the 4th of July, 1834, at New York. When Robertson, the aeronaut, ascended in a balloon from Castle Garden, the wind was from the east, which carried him westward across the Hudson river. At an elevation of about 4000 feet above the earth he dis-

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west, nearly two-thirds of the year; or in the ratio of 15,830 to 8785, while the northerly winds are to the southerly as 1190 to 1231. In the southern portion of the Union below 35°, eastern winds predominate over western in the ratio of 3102 to 1717; from which it would seem that they are subject to the general influence that governs the regular trade-winds of the tropics. In the same section of country, northern winds are to southern in the ratio of 508 to 721.

As Cincinnati, lat. 39° 06′, affords a tolerable specimen of the Ohio valley generally, it may be stated that western winds prevail over eastern in the ratio of 631 to 325; while at New York, lat. 41°, they are as 580 to 279. They are also nearly in the same proportions throughout the Atlantic Ocean, between North America and western Europe. (*See Darby's View of the United States.*)

Mr. Daniell states, that upon an average of ten years, westerly winds exceed easterly in the ratio of 225 to 140 in Great Britain; while northerly winds are to southerly, as 192 to 173.) *Meteorological Essays*, p. 114.) During spring, the prevalent wind is from the dry, cold, northeastern regions of Russia, Sweden and Denmark. Throughout the Mediterranean, Egypt, Palestine and the south of Europe generally, the wind blows nine months in the year from the northern points of the compass; because situated between the cold regions of Arctic Europe and Asia and the burning plains of Africa, where the temperature is from 100° to 113° F. in the shade, and upwards of 120° in the great deserts.

appeared in a mist or cloud, when he met with a counter-current from the west, that brought him back over the city, and landed him ten miles to the eastward of Long Island. It is quite evident that the canopy of clouds, which overspread the city and country in the afternoon, was condensed by the colder upper current from the west.

From the 7th until the 10th of July, (1834,) the heat was excessive, ranging from 86° to 96° F. in the shade, while the wind was from the southeast. On the 10th, about noon, the wind prevailed from the west, condensing the vapour of the heated air into floods of rain, attended with violent thunder and lightning. It is thus that a *land-wind*, which usually brings fair weather, causes precipitation, by meeting with a southerly wind charged with aqueous vapour. It is highly probable, that at all times when rain attends a southerly wind, and when the land temperature exceeds that of the sea, precipitation is owing to the prevalence of a colder upper current from an opposite direction.

What can be more impressive and sublime than those great movements of the atmosphere, by which the waters of the ocean are wafted over continents and islands; pestilential vapours dispersed; the face of nature refreshed and adorned with living robes of surpassing beauty? In his usual metaphorical style, Lord Bacon speaks of winds as the wings of commerce. They are also the great natural ventilators of the earth by which the dry land is furnished with pure air from the ocean, whose waters absorb the car-

bonic acid contained in it. Were it not for this constant interchange of air between the tropical and higher latitudes, the earth would be scorched by insupportable heat during summer, and blasted by the rigours of deadly cold in winter. But in the present order of things, such hurtful extremes are prevented by a never-ceasing circulation of the atmosphere from one zone to another.*

If the whole earth were of uniform surface and elevation, its temperature would be the same in given latitudes and seasons, and the currents of the atmosphere would present a succession of regular movements. There would be no sudden mixing of winds

* By the agency of warm southerly winds immense masses of aqueous vapour are transported from the ocean over North America to the higher latitudes, where, meeting with a body of air from the frozen regions, it is condensed into cold rains or extensive falls of snow, according to the season of the year; while the northern atmosphere is thus warmed by the disengagement of caloric from southern vapour.

If southerly winds prevail for a long time from the ocean during autumn, until the atmosphere is saturated with vapour over a large portion of the northern hemisphere, without meeting with a mass of northerly air to condense it, the commencement of winter is marked by an extensive fall of snow, from a foot to eighteen inches, or even three feet in depth,—over which the polar winds pass without being warmed, to the lower latitudes, causing excessive winters. This is one reason why during some winters in the United States, the temperature occasionally falls from 30° to 40° lower than during others. After such a fall of snow the wind has prevailed for six weeks together, from the northern points of the compass, as in the winter of 1779 and 1780, and about the same length of time during the winter of 1834 and 1835, when the mercury fell from —20° to —40°, in latitude 35° to 43°. I shall have more to say on this subject in another place.

from opposite quarters, and no lightning nor rapid precipitations of rain, because there would be a regular gradation of temperature and density of the atmosphere from the equator to the poles. But, as the surface of the earth is diversified by land and water, mountains and valleys, hills and plains, unequal temperatures in the same latitudes and seasons result, causing all those irregular movements in the atmosphere termed variable winds; and which can never be predicted with unerring certainty until all these modifying circumstances are classified and reduced to general laws.

THEORY OF HURRICANES, HAIL-STORMS, WATER-SPOUTS AND TORNADOS.

Having shown in the preceding chapter, that lightning is always attended with the precipitation of atmospheric vapour, I proceed to prove that *no violent squall, hurricane, tornado or water-spout, ever occurs, without the sudden condensation of aqueous vapour, by which a vacuum is formed, causing a rush of air from different quarters.*

The typhon of the Greek philosophers was a hurricane, accompanied with vivid flashes of lightning, which they called fire; while the tornado was described by the Romans as *vortex igne factus*, meaning a whirlwind made by fire. It is evident on the slightest reflection, that violent winds which spring up suddenly, and often immediately after a calm, cannot possibly be owing directly to the rarefying influence of solar heat, like regular winds, the velocity of which

rarely exceeds twenty or thirty miles per hour;* whereas the tornado moves at the rate of from one hundred to one hundred and twenty miles per hour. It is during the rainy season, that the tropical regions are visited by those dreadful hurricanes or fiery tempests which tear up trees by their roots, destroying everything in their resistless course, and when rain is precipitated in floods with a rapidity proportional to the amount of lightning. Those of the East Indian seas occur during the shifting of the monsoons, and are obviously owing to the condensation of vapour, caused by the meeting of extensive masses of air from opposite quarters, of different temperatures. The equinoctial storms that sweep over the West Indies, the Gulf of Mexico and the southern portions of the United States, are also produced in the same way, and are attended by extraordinary floods of rain, with fearful displays of thunder and lightning. An eye-witness of the tremendous hurricane which desolated the island of Barbadoes on the 10th of August, 1831, informed the author, that it began about ten o'clock at night, with torrents of rain and broad sheets of fire in rapid succession, which threatened to over-

* —— We often see against some storm
A silence in the heavens, the rack stand still,
The bold winds speechless, and the orb below
As hush as death: anon the dreadful thunder
Doth rend the region.—HAMLET.

The calm is owing to the meeting of large masses of air from opposite quarters, and thus tending to neutralize their movement, until condensation is produced, when the stillness is succeeded by the roaring tempest.

whelm the inhabitants in a flood, or sweep them away in a tempest of flame. This storm swept over St. Lucia, St. Domingo, Cuba, the whole of the Mexican Gulf, Louisiana and most of the southern States. A similar storm occurred on the 12th of August, 1830, at St. Thomas, and extended along the southern shores of the United States over a tract 500 miles in width.

On the other hand, in the tropical portions of the wide Pacific, where the temperature is uniform, and the winds blow steadily in the same direction, there is but little thunder, lightning and rain, and no hurricanes. The same is true of the equatorial parts of the Atlantic, which are far from land. It is stated by Capper, in his account of winds and monsoons, that a hurricane was never known to occur at St. Helena, situated as it is, nearly midway between Africa and South America. It is near the continents of Asia, Africa and America, or in the vicinity of large islands, where immense masses of vapour from the sea meet with mountains and cold masses of air from the land, that hurricanes of wind, lightning and rain, are most powerful and frequent, as in the Bay of Bengal, on the coast of Madagascar, Mauritius, &c. In short, there never was a hurricane, tornado or gale in any part of the world during the existence of perfectly dry weather. It is therefore evident that lightning, and all violent winds, are immediately connected with the rapid condensation of aqueous vapour or steam, which owes its existence to the expansive agency of solar caloric. Even the winter gales, so fatal to shipping on the coasts of Great Britain and France, are

always attended with copious precipitations of rain or snow, and sometimes with lightning.

This may be readily understood when it is remembered, that all the water which falls on the earth existed previously in the atmosphere in the form of steam, which, at the temperature of 60°, is lighter than air in the ratio of 622 to 1000. This steam is confined chiefly to the lower regions of the air, and must necessarily augment its volume in proportion to the quantity diffused through it; the consequences of which are, that *immense vacuums are produced by its condensation and a violent rush of the surrounding air from different quarters, until an equilibrium is restored.*

Perhaps there is no part of the world where thunderstorms are so frequent as in the Bay of Mexico and on the borders of the Gulf Stream. It has been said, that of all the vessels in the world, which are annually destroyed by lightning, two-thirds have been lost on the track of the Gulf Stream.

We may readily comprehend all this when we reflect that the Gulf Stream is a portion of the great equatorial current, (caused by the trade-wind,) which is obstructed by South America and deflected into the Bay of Mexico, where its temperature is from 70° to 80°, according to the season. With its tropical temperature it issues from the Bay of Mexico through the Florida Channel, advancing along the southern coast of the United States northeastward to the Banks of Newfoundland, and thence to the western coast of Ireland, until it is lost. For the distance of 1500 or 2000 miles its temperature is from 10° to 20° higher than that of the ocean on its northern extremity; the con-

sequence of which is extensive evaporation. The vapour thus formed is perpetually meeting with bodies of cold air, by which it is condensed, causing a succession of vacuums, local storms, water-spouts, &c.* We are informed by seamen, who navigate the Atlantic between the United States and England, that while one vessel encounters a thunder-storm, others enjoy mild breezes within thirty or forty miles of the same place.

The same general agency, modified by the relative position of land and water, oceanic currents, mountains and valleys, operates to a greater or less extent over all the earth. Off Cape Hatteras, which is washed by the Gulf Stream, there is a constant succession of gales, which are obviously caused by the mingling of warm and cold air, as seamen always observe a sensible change of temperature on passing the Cape. The same cause renders the Cape of Good Hope a theatre of perpetual war of conflicting tempests, occasioned by the difference of temperature between the great equatorial current, as it doubles the Cape, and the colder water of the Southern Ocean.

The streaked and forked appearance of ordinary

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* As many as sixteen water-spouts were seen at the same time by Captain Lawrence on the borders of the Gulf Stream, in lat. 32° 48′, when off Charleston, on a voyage from New Orleans to New York in 1834. They are all formed by the sudden condensation of aqueous vapour, caused by the meeting of opposite currents of air that deflect each other, producing a funnel-shaped cloud, that descends in torrents of *fresh*, and not salt water, as has been generally supposed. In short, they are what Franklin termed them, whirlwinds at sea.

lightning are optical illusions, which result from the rapid passage of the electric spark through the air, which makes an impression on the optic nerve that remains during its passage, in the same way that a burning stick, when involved, presents the appearance of a continuous circle of fire. The fork is owing to a division of the original spark or ball into two or more sparks, which diverge from each other. The zigzag appearance is owing to frequent slight deflections of the spark, as it moves through strata of air of different densities. Whenever an electric explosion takes place near to the spectator, it always presents the appearance of a ball of fire, attended by a simultaneous report, like that of artillery. The reason that the report is usually heard many seconds after the flash is seen, is owing to its distance from the point of observation and to the slowness with which vibrations are propagated through the atmosphere; while its rumbling or prolonged existence is owing to the space over which it passes.* The report itself is probably caused by a sudden collapse of the air as it fills the vacuum produced by the passage of the electric bolt through it; and by its violent collision against the air, causing a tremour of the atmosphere to the distance of many miles, which is communicated to buildings

* For example, sound travels through the air at the rate of 1130 feet per second; so that 60 seconds, or one minute, must elapse before it can be heard at the distance of 12·84 miles, becoming fainter as the more distant vibrations reach the ear. And we may easily ascertain the distance of the flash by looking at the second-hand of a watch, until the report is heard.

and other solid bodies.* It is likewise probable that the luminosity of the spark is owing to a sudden combustion of air or vapour by so intense a heat.

It was first observed by Dr. Franklin, that the cold summer gusts of the middle latitudes generally come from the west; from which he concluded that they were caused by a descent of cold air from the upper current of the atmosphere, on its passage from the equatorial to the polar latitudes.

That this is the true mode of accounting for many of our thunder-storms, would appear reasonable from the following considerations. They occur during the most sultry weather and hottest time of the day, generally the afternoon, when the lower atmosphere is greatly rarefied, so as to favour a descent of cold air from above, which rapidly condenses the transparent vapour of the lower atmosphere into floods of rain, that are often attended with hail, and always with a great reduction of temperature. In this way clouds are often formed suddenly, the whole sky becoming obscured by dense black clouds, accompanied with thunder and lightning, violent winds and copious precipitations of rain. During such storms, more vapour is condensed into rain in twenty or thirty minutes, than usually falls during a whole day, or even a week

* This was proved by Beccaria, who constructed a glass siphon, in one leg of which air was inclosed above a column of mercury, and compressed by the column in the other leg of the siphon. On discharging a Leyden jar through the air thus inclosed, the column of mercury in the other leg was suddenly elevated, and recovered its position after several oscillations. (*Electric. Artific.*, Turin, 1753, p. 227.)

when there is no lightning. All the phenomena partake of the violence which characterizes discharges of the electric fluid when greatly accumulated.

Lord Bacon observes, in his *Natural History of Winds*, that "tornados are caused by the *sudden breaking of clouds*," by which he meant those rapid precipitations of rain that accompany lightning and thunder. And we often hear from seamen that *a violent hurricane issued out of a dense cloud.* Bacon observes again, that "*when it lightens in a clear sky*, winds and rain are at hand from the quarter where it lightens: but if it lightens in different quarters, there will follow cruel and horrid tempests." He might have added, that they have already begun in the places where the lightning is seen.

HAIL-STORMS.

On the subject of hail-storms, which are intimately related to whirlwinds, water-spouts, &c. much learning and ingenuity have been expended since the days of Franklin, without any satisfactory explanation of their cause.

The celebrated Volta supposed that they were produced by "an highly electrical condition of the atmosphere; that the frozen masses were kept in a state of reciprocating motion between two clouds, oppositely charged with electricity, until the mass rendered the force of gravity predominant; or until the electric tension of the cloud was exhausted by mutual reaction." In his report on the present state of meteorology, Pro-

fessor Forbes observes, that no better solution has yet been offered to the world. (*Transactions of the British Association*, vol. i. 1832.)

The leading facts connected with hail-storms are the following:—

1. They are generally confined to the middle latitudes, where masses of cold air from the polar regions meet with warmer air from the tropical latitudes, loaded with aqueous vapour. When such currents encounter each other at the usual height of spring and summer clouds, the vapour of the warm air is condensed into cold rains, or showers of small hail, but without much lightning or violent wind; whereas all the most destructive hail-storms are accompanied with tremendous flashes of lightning, and often with fearful whirlwinds, or tornados.

2. They occur chiefly during warm weather in the United States, when the lower atmosphere is full of vapour, and heated to the temperature of 80°, and sometimes 90° F.

3. They usually run in veins of limited extent, and are most frequent in level districts, especially such as are hemmed in by mountains, as in the south of France, where they are very destructive to the crops.

4. They are often attended with the sudden precipitation of immense quantities of ice, which descend in large globular masses, and always with a great reduction of temperature.

Several of the above facts are exceedingly difficult to explain, without admitting the hypothesis of Franklin in regard to the cause of thunder-gusts; that is, a sudden descent of cold air from the upper regions, by

which the vapour of the lower atmosphere is rapidly condensed and congealed into globules of ice.

In opposition to this view of the subject, it is maintained by Dr. Thomson, that the upper air cannot descend without undergoing condensation and giving out a portion of its latent caloric, which he thinks would prevent it from cooling the atmosphere. (*Treatise on Heat and Electricity*, p. 129.) Whatever may be the just weight of this objection, the fact is certain, that aqueous vapour is suddenly and rapidly congealed by very cold air; by which the temperature of the lower atmosphere is often reduced from 80° or 90° down to 32°, or even less, within a few minutes, during extensive and violent hail-storms.

It is also certain, that a vacuum must be formed in the lower atmosphere proportional to the volume of vapour thus suddenly condensed; the extent of which may be estimated from the vast quantities of hail that are occasionally precipitated in a few minutes, amounting to a depth of nine inches in as many minutes, according to M. Pouillet. The formation of such a vacuum is always attended by a rush of air from opposite quarters, creating a gyratory or whirling motion, the force of which is in proportion to the extent of the vacuum and the rapidity of its formation.

That the reader may perceive the more readily how intimate is the connection between lightning, the condensation of vapour, hail-storms and whirlwinds, it may be proper to present a brief account of a few thunder-storms which have occurred in Great Britain:

On the 10th of August, 1835, Durham was visited

by a violent whirlwind, accompanied with incessant lightning and thunder. At seven o'clock P.M., a most vivid flash of lightning struck the cathedral, and hurled down an immense mass of stone that killed two of a party of students, who at the moment fled from the interior of the cathedral.

"On the same day Chesterfield was visited by a violent storm of thunder, lightning, rain and hail. A large ball of fire fell in the Commercial Inn yard, where there was an accumulation of water, splashing it in all directions into spray, which for a moment seemed to be enveloped in flames.

"Many such storms occurred about the same time in different parts of England, Scotland and Ireland. On the 10th of June, about three o'clock, there was a storm of lightning, thunder and hail, at Dumfries,—and at Ardach on the following day, there was a violent thunder-storm, where the drifted hail was two feet in depth in some places, and remained on the ground for twenty-four hours.

"At Sheffield, during a thunder-storm, the electric fluid entered the works of Mr. Ellin, and struck a pile of ivory-handled knives, the blades of which were fused into one mass, and the hafts split off in a singular manner. Twelve individuals were thrown down; they supposed that the boiler of a steam engine in the room had bursted.*

* It is related in some of the older books on natural philosophy, that Erfurt, a small city of Germany, was struck by lightning during a storm, in forty-two different places. Seven persons were killed, and three houses set on fire, which were quenched by the rain, that fell in torrents.

"On the 6th of June, forty-two head of cattle were killed by lightning in one field, at Johnstown, near Tuller. Some had their heads and horns burnt, and some their shoulders. On the lands of Mr. Lynham, at the Hill of Talloght, eighteen cattle, twenty-three sheep and a goat, were also killed by lightning." (*Bell's Weekly Messenger*, June 14, 1835.)

TORNADOS OF THE UNITED STATES.

It was observed by Lord Bacon, that "all tornados or great whirlwinds have a manifest precipitous motion, or darting downward more than other winds, so that they seem to fall like torrents, and run as it were in channels."

Such tornados are remarkably frequent in the United States during hot sultry weather, and are attended with the most striking displays of electrical phenomena: always with rapid condensations of vapour, and often with enormous quantities of hail. They generally run in narrow veins from 100 yards to half a mile wide; while the equinoctial hurricanes of the Southern States, like those of the tropics, sweep over a vast extent of surface, and are rarely if ever accompanied with hail. The tornado is sometimes attended by a rapid succession of lightning; at other times it presents the appearance of an inverted fiery pyramid,

On the 15th of August, 1836, twenty-eight houses were set on fire by lightning in the town of Grundelbruch; while at Villexon, nineteen dwellings were consumed about the same time, during a thunder-storm, attended with hail and a tornado. (*Galignani's Messenger.*)

from which is heard a continuous roll or deep roar of thunder, like that of a heavy unremitted cannonade, the sound of which is greatly modified and obscured by the noise of the raging wind, crashing of buildings, falling timber, &c.

The whirlwind which destroyed a large portion of New Brunswick, in the State of New Jersey, on the 19th of June, 1835, presented many of the above phenomena. Those who witnessed its commencement, observed the formation of several inverted cones of dense black vapour, which descended from the upper regions. Dr. Lewis Beck describes one of these "as resembling in appearance the eruption of a volcano, which produced the impression, at a distance, that some large building had been set on fire by lightning, a vivid flash or two of which had preceded the formation of the cones. But in a few minutes the dense column was dissipated, when another black and well-defined cone was formed, which remained stationary for a short time, and then gave place to the eruptory appearance and gyratory movement that characterized the other. The first occurred about three miles west of New Brunswick. But when the second movement commenced, a dense black cloud overshadowed the city. Slight, but distinct explosions were heard from the column in rapid succession, like the bluffing of sails. Volumes of smoke and flame were thought to be issuing forth, and rolling over in various directions, when the idea of an extensive and rapid conflagration was suggested. The alarm bells were rung, and the firemen repaired to their engines. But while all eyes were directed to the black and dreadful column that

was approaching, no one could fix upon the exact spot to which efforts should be directed. This uncertainty was soon removed by the desolating progress of the whirlwind through the city, prostrating houses, and wafting heavy beams of timber to a great distance." Like most tornados, it was attended with hail, as well as rain. The width of its tract varied from 100 feet to 200 yards, in the neighbourhood of New Brunswick; while three miles eastward it was half a mile wide. A writer in the New York *Times* states, that on the banks of the Raritan, for 1000 yards, vegetation was scathed, as if a flame had passed quickly over it.

Similar storms desolated different portions of the Union about the same time. "Late in June, Lynchburg, in Virginia, was visited by a tremendous whirlwind and tempest of hail, which was preceded for several minutes by a monotonous rumbling sound, resembling the bass tones of distant thunder or the deep roll of the muffled drum; and reminding us of the ominous notes which precede an earthquake." (*Lynchburg Virginian.*) Dense black clouds are described as pouring forth immense masses of ice, and so darkening the air, that houses within a few paces were totally invisible.

During the summer of 1834, which was unusually sultry, tornados and hail-storms of limited extent, visited almost every State in the Union, from Maine to Louisiana; several of them attended with great loss of lives and property. In most cases, they pursued a course from west to east.

About the 20th of March, 1832, a tornado occurred

in the southern portion of Tennessee, lat. 35° N. which differed in some respects from any of the preceding.

After several remarkably warm days for the season, accompanied with a southerly wind, a tornado came on suddenly, without the slightest warning, about seven o'clock P.M. It excited great astonishment, as the whole day had been warm, serene and clear, with the exception of a slight haziness, up to the moment when the crashing noise of falling timber announced the approaching storm from the northwest. The temperature was immediately reduced several degrees below 32° F. and attended with a rapid fall of snow, which continued for several hours; but the tornado blew with violence for only about ten minutes. The next morning, the wind was cold and northwesterly, and continued northerly for two days.

This storm seems to have been owing to the prevalence of a cold upper current from the north, which met and mingled with the warm southerly air, and suddenly congealed its vapour into snow. It had not the local character of the summer tornado; for it was followed by great cold *over a large extent of country.*

I shall close this imperfect history of thunder-storms with the account of an extraordinary and sudden coldness which occurred in the island of Cuba, on the 24th of May, 1809.

Cornelius Roberts, a sugar and coffee planter, who resided forty years on the island, informed the author, "that after a hurricane had been blowing from the southeast and south, from the 22d until eleven o'clock A.M. of the 24th, a calm followed for an hour,

when the wind prevailed from the northwest. At the same time, the atmosphere became extremely dark, like night, accompanied with a roaring in the air, tremour of the earth and intense cold. Everything green was killed and became black, as if a fire had passed over the country for several miles in breadth, and about sixty miles in length:" which proves that a mass of air may descend from above and refrigerate the lower atmosphere of the tropical regions, as in the middle latitudes, though such a phenomenon is extremely rare.

CHAPTER III.

INFLUENCE OF TERRESTRIAL TEMPERATURE ON THE BAROMETER.

It has been long known that the fluctuations of the barometer are intimately connected with all the phenomena of meteorology; that during winter, in the middle and higher latitudes, its depressions are followed by rain, snow and tempestuous weather; while its rising is accompanied with cold, frosty and dry weather; and that during summer its falling forebodes storms of thunder, lightning and rain, which are often attended with violent hurricanes; while its rising indicates clear and serene weather. Yet the theory of its variations has never been clearly reduced to the simplicity of established principles. Without stopping to examine the relative merits of those who have devoted their attention to this difficult and important problem, it may be observed without injustice to any, that we are chiefly indebted to the labours of Dr. Dalton for the true mode of investigating it.

The most important facts connected with the barometer may be reduced to the following propositions:—

1. *The mean height of the mercurial column at the level of the sea, is nearly the same over all the earth, the average amounting to about thirty inches.*

2. *The density or specific gravity of the atmosphere increases gradually from the equator to the regions of lowest mean temperature, corresponding with the decrease of temperature; the consequence of which is, that the height of the atmosphere must diminish from the equator to the poles.*

3. *Within the tropics, the temperature is always nearly the same: the range of the barometer is also small, varying from two lines to a quarter of an inch.*

4. *The range of temperature augments from the equator to the regions of maximum cold: the variation of the barometer augments in a corresponding ratio,—amounting to about three inches in the coldest latitudes.*

The range of temperature is much greater in North America than in the same latitudes of Europe, as will appear from the following facts. During the winter of 1831 and 1832, the thermometer fell to —20° at Florence, in the State of Alabama, lat. 35° N., and —40° at Plattsburg, lat. 44°, where it sometimes rises to 95°, and even 100° during summer, making its extreme annual range from 130° to 140° F.* The diur-

* It is, however, but seldom that the temperature falls below 0° in the States south of Philadelphia and New York; so that the usual annual range does not much exceed that of England, which is about 80°, according to Mr. Daniell; that is, from 11° to 90°. Hence it is, that the mean range of the barometer is about the same in Great Britain that it is in the middle States of America, as observed by Dr. Dalton forty years ago. Perhaps there is no part of the world where the fluctuations of temperature are more frequent than in England; the reason of which is obvious from its insular and geographical position, being situated about midway between the burning plains of Africa to the south, and the frozen regions of the north; while on the east and northeast it is in-

nal variation is also very great, as the thermometer often rises to 90° in September and October, during the hottest part of the day, and falls below 32° at night, making the daily range of temperature 60° F.

Still more extraordinary are the changes from heat to cold in those extensive regions of North America beyond the limits of the United States, which have been explored by Scoresby, Parry, Franklin, Ross and other British navigators. We are informed by Captain Back, that on the 17th of January, 1834, the thermometer was —70° F. at six A.M. on the Great Slave Lake, lat. 62° 46′; but rose to 45° in the afternoon of the same day,—making a diurnal range of 115°. He also states, that on the preceding day the temperature rose to 52°; while the long summer days were often oppressively warm. Hence it is, that as we approach the polar regions, we find the winds irregular and variable, coinciding with the frequent changes in the density of the atmosphere and consequent fluctuations of the barometer.

5. Corresponding with the foregoing facts, *the barometer rises to the greatest height during cold northerly winds in the middle latitudes, and falls during warm southerly winds.* That is, a mass of air from the torrid zone is specifically lighter than one from the polar regions, and must cause a proportional fall of the mercurial column, until the equilibrium is restored. For example, the maximum height of the barometer at Philadelphia was on the morning of May 5, 1847,

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fluenced by Sweden, Poland, Russia and the cold elevated plains of Tartary; and by the Atlantic Ocean on the west; all of which contribute their share successively in forming the climate of Britain.

when the wind was from the northeast; but the minimum was on the 29th, at noon, when the wind was from the southwest, and the temperature 94° F. On the next morning the wind was from the north, and the temperature 52° at nine o'clock in the evening, having fallen 42° in 31 hours.

But in addition to the immediate agency of temperature in modifying the specific gravity of the atmosphere, the amount of aqueous vapour diffused through it exerts a material influence. It has been already shown that the quantity of vapour in the atmosphere, *cœteris paribus*, is proportional to temperature; the greater part of this is confined to its lower strata, (within two or three miles of the earth's surface;) and at the temperature of 80° F. the atmosphere is capable of containing an amount of vapour equal to the pressure of an inch of mercury, or one-thirtieth of its whole weight. If, then, we take the estimate of Gay-Lussac, that the specific gravity of aqueous vapour is less than that of air at the same temperature, in the ratio of six to ten, it is evident that the specific gravity of the atmosphere must be diminished in proportion to the quantity of vapour diffused through it. Hence it is, that warm southerly winds, which have been expanded by heat and charged with vapour, cause the barometer to fall. It also follows, that as rains are supplied chiefly by warm southerly winds, in the middle and higher latitudes of the northern hemisphere, the sinking of the barometer must be an indication of falling weather. And as it has been shown that all violent winds, such as hurricanes, tornados, &c. are owing to the rapid condensation of aqueous vapour, the falling of the baro-

meter must also forebode tempestuous weather. It is equally evident, that currents of cold air raise the barometer, not only because of their greater specific gravity, but because they condense the steam of warm air. Hence it is, that for two or three days before storms of thunder and lightning, wind and rain, during the prevalence of warm southerly winds, the barometer falls; but rises during cool and serene dry weather.*

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* From several passages in Mr. Daniell's work on the atmosphere, it would seem that he referred the sinking of the barometer to the evolution of caloric from aqueous vapour during its condensation, by which the atmosphere is expanded where it takes place. But it has been shown that within the tropics, where the amount of condensation is greatest, the fluctuation of the barometer is very small; while it is obvious from the foregoing facts and observations, that the barometer is depressed by the accumulation of aqueous vapour in the atmosphere, and elevated by its condensation.

Dr. Dalton ascertained by a series of observations continued for five years at Kendal, in the north of England, that the barometer fell below twenty-nine inches during forty days, only two of which were fair; but that when it stood above its mean monthly height, there was but little rain, and generally fair weather.

He also found that the heaviest rains fell when the barometer was about 29·47, and not when at a minimum, as might have been expected, *à priori*. His explanation of this fact is simple and ingenius. He observes, that "when the barometer is above the mean high extreme for the season of the year, the air must, relatively speaking, be extremely dry or cold, or both. If extremely dry, it is in a state for absorbing vapour; and if extremely cold, no further degree of cold can be expected, and therefore in neither case can there be any considerable precipitation. On the contrary, when the barometer is very low for the season, the air must relatively be extremely warm, or extremely moist, or both; if extremely warm, it is in a similar state to dry air for imbibing vapour; and if extremely moist, there must be a degree of cold introduced to

6. *The range of the barometer is greater during winter than summer in the middle latitudes.*

The reason of which is, that the advancement of the sun toward the pole brings the temperature of the higher latitudes to nearly an equality over forty or fifty parallels, and almost to the same state as within the tropics, as observed by Dr. Dalton: whereas during winter, the warm and rarefied air of the tropical regions is often encountered by widely extended currents of cold dense air from the polar latitudes; the consequence of which is, that the barometer will rise or fall at the same time, over a great extent of country, according as the warm and vapoury or cold and dry currents of air predominate, and will be greatest when the extremes of temperature in the opposing currents are at a maximum.

7. *The regular elevations and depressions of the barometer, termed its horary oscillations, follow the daily fluctuations of temperature.*

According to the observations of Mr. Daniell, the daily average height of the barometer at London is ·010 inch higher at night than the afternoon,—and ·005 inch higher in the morning than at night; it is therefore ·015 inch higher in the morning than the afternoon. (*Essay on the Climate of London.*) The daily variation is still greater in the interior of North America, lat. 41° 25′ at the Rocky Mountains, where Colonel Long found the mean height of the barometer, in

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precipitate the vapour, which cold, at the same time, raises the barometer. From which it follows, that no very heavy and continued rains can be expected to happen whilst the barometer remains about the lowest extreme." (*Meteorological Essays*, p. 143.)

March, 28·713 inches in the morning, 28·609 at noon and 28·630 at night.

From the observations of Captain Sabine and others, it would seem that the *diurnal variation* of the barometer is greatest at the equator, where the power of the sun's heat is a maximum, and diminishes on approaching the polar circles, as shown in the following table, given by Mr. Daniell:—

At St. Thomas,	lat. 0·24′	the diurnal	variation	was ·074	inch.
Trinidad,	" 10·39′	"	"	" ·063	"
Jamaica,	" 17·56′	"	"	" ·058	"
Paris,	" 48·50′	"	"	" ·028	"

Finally, all the variations of the barometer are greater at the level of the sea than in high situations, corresponding with the greater fluctuations of temperature of the lower atmosphere.

DEW AND FROST.

After the setting of the sun, the surface of the earth is cooled down by radiation from 12° to 15° F. below the temperature of the superincumbent atmosphere; it then abstracts caloric from the stratum of transparent aqueous vapour immediately over it, by which it coalesces into dew, or crystallizes into frost, according to the temperature of the surface.

If the atmosphere be full of vapour, there is a large deposition of dew during summer, on perfectly clear nights; but during spring and autumn, instead of heavy dews, we have large white frosts, which are generally followed in two or three days by rain; of which

they are regarded by the people as a sure indication. But when the cold is more intense, and the atmosphere contains less vapour, we have what is called a black frost, which is attended with a congealed state of the ground. As a general rule, the quantity of dew is in proportion to the amount of invisible vapour in the air, and to the difference between the temperature of day and night. It is profuse in hot climates, and more abundant on continents than islands, *cæteris paribus;* while on the ocean, far from land, there is little or no dew, because the difference between the temperature of day and night at sea is only two or three degrees. In the United States of America, the difference is sometimes 60° F., the consequence of which is a copious deposition of dew, resembling the effects of a shower of rain. It is also copious in England during the prevalence of warm winds from the ocean.

All other things being equal, a greater amount of dew is condensed between midnight and sunrise than between sunset and midnight, according to the observations and experiments of Dr. Wells—obviously because the surface of the earth is then colder, from the loss of caloric by radiation. Dew, then, is not condensed and precipitated like rain by the coldness of the atmosphere, but by the coldness of the earth's surface, which is proved by the well-known fact that dew and frost are formed on the under surface of planks, &c. as well as the upper.

It has been long known that little or no dew is formed under a cloudy canopy, but that it is abundant during clear nights. Dr. Wells referred this circumstance to the obstruction of caloric radiated from

the earth's surface by clouds. It is extremely probable, however, from his own statement of facts, that he mistook a mere concomitant for the real cause of the phenomenon. He informs us, that when clouds begin to form during the night, the surface of the earth rises several degrees, and that dew formed during clear intervals often evaporated again when the sky becomes thickly overcast; from which it would appear, that the caloric evolved from aqueous vapour during its condensation into clouds, warms the atmosphere and prevents the surface of the earth from being cooled to the dew-point. Admitting that a portion of the caloric radiated from the surface of the earth, is reflected back, instead of being absorbed by clouds, it is insufficient to produce so decided a change of temperature. During clear and serene nights, when no caloric is given out to the atmosphere by the condensation of vapour, the earth is cooled down by radiation, because it receives nothing to compensate for the loss of what is given off; so that the transparent aqueous vapour of the lower strata of the atmosphere is condensed into dew. There is no dew on windy nights, for the same reason that evaporation is accelerated by wind; or that a renewal of water and agitation promote the solution of salts.

It was before stated, that caloric is radiated more copiously from rough surfaces than from such as are smooth. In accordance with that general fact, we find that dew is formed more copiously on swansdown, wool, cotton, raw silk, flax, fine shavings of wood, &c. than upon compact pieces of the same materials. It forms more copiously on rough metals than on polished

ones; doubtless because the former present a more extended radiating surface. (See *Theory of Radiation*, book ii. chap. i.)

MISTS AND FOGS.

The formation of all fogs is owing to a partial condensation of aqueous vapour, caused by the abstraction of caloric from colder bodies—often by the mixture of air of different temperatures near the earth's surface. For example, during autumn, the temperature of the Mississippi, Ohio and other great rivers, is nearly the same during night and day; while that of the land is greatly reduced at night by radiation, especially toward morning, when it is at the extreme of reduction. Under such circumstances, the intermixture of the land atmosphere at the temperature of 35° or 40° F., with that of the water, which is from 50° to 60°, produces a fog or mist. The same effect is produced on the eastern coast of the United States during autumn. The land is cooled down by radiation at night, while the temperature of the ocean and the air over it remains nearly the same. During this state of things, whether the wind blows from the sea or land, a mixture of warm and cold air produces fogs.

Over the Banks of Newfoundland, where the warm air from the Gulf Stream is intermixed with that of the cold water and icebergs of the north, they prevail throughout the year. Nova Scotia is, proverbially, the region of fogs. The dark and thick fogs of England occur during the latter part of autumn and win-

ter,—owing to the more rapid cooling of the land by radiation, than of the surrounding ocean.

The frost rime of the polar seas is produced in the same manner as fogs, but by the agency of a lower temperature.

During summer, mountains are generally covered with fog in the morning, when the weather is serene and clear. Being cooled down at night by radiation below the dew-point, they abstract caloric from the transparent aqueous vapour that is always mixed with the atmosphere in greater or less quantity, by which it is condensed into huge volumes of mist or fog, which envelope the mountains with giant folds of majestic drapery, and which are not redissolved by the solar rays before nine or ten o'clock in the morning.

INDIAN SUMMER.

In all parts of the United States, there is an autumnal period of most delightful weather, which usually commences late in October, and continues with occasional intermissions through the greater part of November, during some seasons, in the Mississippi valley, until Christmas. It is generally attended with a southerly wind, which, being warm, is filled with transparent aqueous vapour. But as the earth becomes gradually cooler on the approach of winter, by radiating more caloric than it receives from the sun, the air over it is also cooled down; the transparent vapour is slightly condensed into a fine hazy mist, which reflects and refracts the solar rays in such a manner as to produce the most rich and softened lus-

tre of the bluish-purple and golden air, which continues until there is a change of wind—sometimes, for three weeks in succession. As the Indian summer is generally a dry season, and as the mountains and prairies are frequently on fire during such weather, the hazy appearance of the atmosphere has been attributed by many persons to the vapour of burning substances diffused through the air. But this cause is altogether too limited in its operation to account for the prevalence of Indian summer throughout the greater part of the American continent; and often many hundred miles from burning prairies. The conflagrations that occur during this season are local and transitory; while the gradual cooling down of the earth, during the prevalence of warm southerly breezes, is all-sufficient to account for the phenomenon. The same cause produces in England dense and gloomy fogs, during the same beautiful season in America. This is readily understood, when we reflect that England is surrounded by the ocean; that its atmosphere is much nearer to the point of saturation by aqueous vapour, than that of a large continent; and, therefore, that the same or even a less reduction of temperature must occasion denser fogs and darker days in Great Britain and other insular countries of the higher latitudes, than in continental regions.

The Indian summer of the United States is closed by the commencement and predominance of northerly winds, which condense the aqueous vapour that has been borne from the ocean by southerly breezes, causing dark, cloudy weather, and general rains or snows,

according to the latitude and elevation; after which the reign of winter is established, and the air becomes dry, clear and cold, except in the neighbourhood of the lakes or of the ocean, where it partakes of an insular character.

AURORA BOREALIS.

Before concluding this general and imperfect survey of the agency of caloric in meteorological phenomena, it may not be improper to notice the leading facts connected with the *aurora borealis and australis*, or the northern lights, as they are commonly called on this side of the equator.

It has been already shown, that the atmosphere and all gaseous bodies owe their volume and elastic force to the agency of an igneous ether which surrounds their atoms—and that after being greatly accumulated in aqueous vapour, it is given out in the form of lightning on the meeting of warm and cold currents of air. We have also seen, that the great aërial ocean is in a state of perpetual circulation from the poles to the equator by under currents, and from the equator to the poles by upper currents; and that the density of the atmosphere increases as we advance from the tropics, to the points of lowest mean temperature: from which it follows, that caloric must be evolved by the tropical atmosphere as it passes from a rarer to a denser state. It is equally certain, that the tropical air must carry with it a considerable proportion of aqueous vapor, that must be condensed into fogs or clouds, rain or snow; which accounts for

a very common attendant of the aurora, viz., a low, black cloud, apparently beyond it, and near to the horizon.

M. Hansteen, who has travelled much in the north of Europe and Asia, observes, "that while the auroræ are streaming, the sky becomes opaque or misty." He further states, that "it is a matter of common observation in the arctic regions, confirmed by long experience, that the aurora is usually followed by intense cold, especially after a mild day;" doubtless, for the same reason, that warm and sultry weather in the middle latitudes is rendered cool by a thunder-storm; viz., by the mixture of cold with warm air.

M. Hansteen has given a singular explanation of the aurora, which shows how vague and indefinite the views of philosophers still are in regard to the origin and nature of this beautiful meteor. He observes, that "it is probably the result of a struggle of powers put in activity by the variously constituted substances composing the mass of the earth, which we may one day, perhaps, learn to know." He thinks, that "it produces the arctic fogs, by decomposing the aqueous vapour of the polar atmosphere." (*Edin. Phil. Journal*, vol. xii.)

It has been asked, why the auroræ are not continually formed, as the atmosphere is constantly flowing from the tropical to the higher latitudes. We might as well be asked, why there is not perpetual thunder and lightning while the atmosphere is moving from the sea over the land, charged with aqueous vapour. The condensations which occur in both cases are local and temporary, and depend on the relative

temperatures of different aërial masses. When the upper current of rarefied air from the tropics, charged with vapour, comes in contact with the cold air of the polar regions, it gives out a large portion of caloric or electric matter, which, not being compressed, as in the lower atmosphere, expands like the electric spark in an exhausted glass tube, into broad bands or zones and columns; filling the sky with halos and crowns of lambent light or undulating coruscations. It is highly probable, that the aurora is given off, during the condensation of the upper equatorial currents with the vapours which they contain, in a mode similar to the evolution of silent lightning on a summer's evening, which is generally very far off, and is seen through numerous strata of atmospheric air, producing a diffused or lambent phosphorescence, which resembles the aurora much more than it does lightning which is near at hand.

Sometimes the whole northern hemisphere presents that kind of luminosity which announces the dawn of morning in the east. At other times the auroræ seem stationary during changes of temperature from heat to cold. They often present the appearance of a bank of light, (resembling the effect of a distant conflagration,) resting on or flanked by a low, dark cloud, which is occasionally illuminated by broad flashes. Captain Bonnycastle, of Toronto, in Upper Canada, observes, that during the formation of all remarkable auroræ, dark volumes of vapour suddenly appeared, within the space comprehended by the arch. (*Silliman's Journal*, vol. xxx. p. 132.) Sometimes, though rarely, the aurora presents the appearance of

a wide arch extending across the firmament, which breaks up into columns or streamers that extend toward the zenith.

Various conjectures have been offered in regard to the height at which the auroræ are formed,—nearly all of which have been founded on imaginary data. Some philosophers have supposed that they must be formed at a great elevation, because they have been seen at the same time in very distant countries, as England and America. But it would be quite as reasonable to conclude, that ordinary lightning is given off at a great elevation, because it lightened at the same time in England and America. There is no rational ground for supposing that the auroræ are formed above our atmosphere, and probably never beyond a few miles; while there is every reason to believe that they may be formed in hundreds of places over different parts of the earth at the same time.

It was the opinion of Franklin, Parry, Ross, Hood and Dr. Richardson, that the auroræ of the arctic regions were frequently not higher than ordinary clouds; and Dr. Richardson thinks that they are always attended with the formation of clouds, or of that kind of haziness which causes a halo around the moon—a very important fact, which would seem to establish their connection with the condensation of aqueous vapour, as suggested by Dr. Franklin.

They are most probably in the upper regions of the atmosphere,* what thunder-storms are near to the

* Most of the appearances presented by the auroræ have been imitated by artificial means. Dr. Priestley inserted with cement,

surface of the earth. The auroræ are seldom, if ever, seen between the tropics, because the upper atmosphere is not condensed there, being of uniform temperature. Even near the earth's surface, there is comparatively little lightning where the temperature is uniform, as over the tropical ocean, and where the wind blows uniformly in the same direction.

It is highly probable, that the electric fluid is nearly all given out, before the upper current reaches the centre of maximum cold; which explains why the aurora is less brilliant at Melville Island, than at Bear

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into the top of a tall receiver, a wire not very acutely pointed. He then exhausted the receiver, and presented the knob of the wire to the conductor, when every spark passed through the vacuum in a broad stream of light, which often divided into a variety of beautiful rivulets, continually changing in their course, uniting and dividing again in the most pleasing manner: thus representing in miniature what has been called the streamers of the aurora. When the wire is electrified negatively, instead of streams of fire, there is an uniform luminous appearance like a white cloud, or like the milky-way in a star-light night, which remains for a considerable time, representing the apparently stationary and diffused light of the aurora. (*Priestley's History of Electricity*, p. 524.)

We can assign no limits to the various phenomena which the electric fluid may exhibit under different circumstances. The medium in which it is formed, in the upper regions of the atmosphere, is doubtless greatly rarefied; perhaps equal to that of a receiver which has been rarefied 100 times. It would seem, however, that the aurora sometimes reaches the surface of the earth. It is related by Bergman, that persons travelling over the high mountains of Norway, have been enveloped in it; and Captain Ross states, that he has witnessed it very near to the surface of the earth; and that it has caused the deflection of his compass needle as much as thirty and forty degrees. M. Hansteen also found that when the auroræ were vivid, the horizontal needle was restless, quivered, and varied from three to five degrees from its ordinary place.

Lake, the Shetlands, Orkneys and many other places in lower latitudes. It also explains why in the coldest regions, as at Port Bowen, Winter Island, &c. the magnetic needle is less often disturbed by it than in lower latitudes; and why in the former places, it was almost always seen by the British navigators southward of them.*

Another important fact, that shows the intimate connection between the auroræ and the change of temperature which the equatorial air undergoes, is, that the northern lights are more numerous and brilliant during the coldness of winter, when the upper currents from the tropics, in their passage to the polar regions are greatly condensed; and that they are then formed in much lower latitudes than during summer.

It is also an important corroboration of this theory, that they are seen in lower latitudes in the middle and eastern portions of America and Europe, than on their western coasts; while the former are known to be much colder than the latter in the same latitudes; which is owing to the prevalence of west winds that blow from the Pacific and Atlantic oceans, and thus temper the middle latitudes of western coasts, by giving them an oceanic or insular climate.†

* It is stated by Captain Scoresby, that the aurora was discovered more frequently south than north of Spitzbergen; and by Sir Edward Parry, that it was generally seen south of Melville Island; from which we may conclude, that the upper current of the atmosphere has acquired nearly its maximum density, and deposited nearly all its vapour, before arriving at the limits of greatest cold.

† The effect is increased by the condensation of aqueous vapour which is brought from the ocean by westerly winds, and which gives

The northern lights are seen much oftener in Vermont, which is a cold mountainous State, between latitude 42° and 44° N. than in France or England; though they are much farther north. This is evidently owing to the excessive coldness of winter in Vermont. General Martin Field has recorded, in the *American Journal of Science*, that, during the year 1830–31, the winter of which was excessively rigorous, the aurora was perceived on fifty-six nights; and that during ten years previously, it was observed eighteen nights on an average, annually, at Fayetteville in the above State. Besides which, it must have existed during many cloudy nights, when it was invisible. But in lat. 70° N. between September, 1838, and April, 1839, M. Lottin observed at Bopekop, in the Bay of Alten, on the coast of West Finmark, 143 auroras, being an interval of 206 days. (*Becquerel, de l'Électricité*, &c. tome vi. p. 205.)

The arched appearance of the aurora is an optical illusion, produced by the limits of vision, according to the laws of perspective; for the same reason that the

out caloric during its condensation and precipitation on the western coasts. Hence, the greater amount of rain which falls on the western coasts of North America and Europe, than on the interior and eastern portions. Hence also, the dryness of west winds in the United States, east of the Rocky Mountains, which deposit their vapour on the western slope, before reaching the interior. In the great Mississippi valley, the east wind is dry, while in the Atlantic States it is often moist during winter and spring. On moving westward, it deposits most of its vapour on the eastern slope of the Alleghany Mountains. These facts enable us to understand why in the vast regions drained by the Mississippi, west winds are dry; while in Britain and France they are wet, and east winds dry.

sky presents a vaulted appearance—or, that clouds present the appearance of a canopy, while in reality they are suspended in horizontal strata. The different apparent heights of the auroræ are owing to their various distances from the points of observation. When the lower atmosphere between the observer and the lights is hazy, they appear irised or rose-coloured; probably for the same reason that the sun rises and sets red, when the lower air is filled with vapours.

The oscillations of the magnetic needle are as variable as the aurora; when the arch is quiet, the needle is often motionless; its disturbance in these cases commences when the streamers begin to fly. The position of the dipping needle has been observed to be as variable as that of the compass needle, the former rising and falling with the corona. The intensity of the magnetism of the needle is also diminished. (Kreil. *Bibl. Univ.*, tome viii. p. 114.)

Siberia, Lapland and the Norwegian Alps, are distinguished by the frequent display of this beautiful and mysterious phenomenon, which I have thus endeavoured to explain in accordance with the best-established principles of meteorology. After all, it is quite probable, that some very important facts have been overlooked, which, if known and rightly considered, might place the whole subject in a new light. It is to be hoped, that fifty years hence, we shall have fifty accurate observers of natural phenomena for one at the present time.

Very little is known of the auroræ in the southern hemisphere, except what has been observed by Captains Cook and Weddel, who relate that they have

been frequently seen south of Van Dieman's Land, and off Cape Horn, where the cold is excessive.*

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* From a general view of the foregoing chapters, it must be obvious:

1. That all the phenomena of evaporation and rain, lightning and winds, hurricanes and tornados, fluctuations of the barometer and formation of the auroræ, are immediately connected with the theory of caloric, and those fundamental laws which govern its distribution over our planet.

2. That the aurora is a thermo-electric phenomenon, produced during the condensation of vapour contained in the equatorial upper current of the atmosphere, on its passage to the polar latitudes, in a mode analogous to the evolution of lightning from the more elastic vapour of the lower and denser atmosphere, on mixing with colder currents, as during thunder-storms.

In opposition to this theory, it is maintained by Dr. Faraday and others, that "the electric equilibrium of the atmosphere is preserved by the aurora conveying electricity from the poles to the equator." Can it be possible that the vast amount of lightning perpetually disengaged within the tropics, and during summer in the middle latitudes, is thus obtained? With sentiments of unaffected and profound humility, the preceding facts are offered as an answer to this query.

CHAPTER IV.

GALVANIC ELECTRICITY.

"Thou mayest babble about electricity, but what is it? whence comes it? whither goes it?"—CARLYLE.

IF we would know what electricity is, we must carefully investigate all the phenomena that make up its natural history. Nor does it become the philosopher to despair of discovering its nature and origin, before he has ascertained what office it performs in the economy of the universe. Thomas Carlyle has done injury to the cause of science, by his want of faith in the well-directed powers of the human mind to comprehend the *mysteries* of nature, for which he seems to have a more profound reverence than for the knowledge of nature.

The first discovery connected with this branch of physical science is found in a German work, published in 1767, by Sultzer, entitled *The General Theory of Pleasures.* He observed, that if two metals be applied, one above, and the other below the tongue, and brought in contact, a peculiar taste was perceived, attended with a gentle flash of light; but that if applied separately, no such effects were produced.

It was next discovered accidentally by Galvani, a distinguished professor of anatomy at Bologna, that

on touching the crural nerve of a recently killed frog, (which lay on a table, near the conductor of an electrical machine in action,) with the point of a scalpel, all its muscles were thrown into convulsions, as if seized with tetanus. By repeating the experiment on different animals, he found that the effect was most remarkable in those which are cold-blooded, and have white muscles. He ascertained afterwards, that when the nerves and muscles of such animals were armed with small pieces of different metals, similar phenomena were produced on bringing the metals in contact.

From these obscure results, Galvani arrived at the conclusions, that there is a peculiar species of electricity in all animals, which resides in the brain, and is conducted to different parts of the body by the nerves, causing animal motion and secretion; and that positive electricity resides in the nerves, and negative in the muscles. He supposed it to be conducted from nerves to muscles by the metallic arc, as the electricity of a Leyden battery is conducted from it by means of a common discharger.

In opposition to the views of Galvani, it was maintained by the celebrated Volta, professor of natural philosophy at Pavia, that the phenomena were due to the agency of common electricity, which he supposed was developed by the contact of different metals.

Finding that when sticks of zinc and copper, zinc and silver, &c. were made to touch at one of their extremities, and the other brought in contact with the spine and muscles of a newly killed frog, convulsions were excited, it occurred to Volta, that by a repetition

of circles, or series, composed of two different metals and moistened cloth, he might greatly increase the electrical effects. This led to the construction of the well known pile, and the *couronne de tasses*, which has been modified into different forms of the battery. In reply to the hypothesis of Volta, that the convulsions of the frog were owing to the agency of common electricity, and generated by the contact of different metals, Galvani objected that he had succeeded in producing convulsions by means of a single metal. And it was further shown by Aldini, a nephew of Galvani, that by bringing a portion of a warm-blooded animal in contact with a cold-blooded one, as the nerve and muscles of a frog with the bloody flesh of a newly decapitated ox, energetic contractions were produced. When he held a prepared frog in his hand, moistened with a solution of salt, and applied the crural nerves of the animal to the tip of his tongue, convulsions were also excited*—from which he inferred, with Galvani, that there is a peculiar electricity in animal bodies which does not require the contact of metals for its development. It is somewhat surprising that he was never led to suspect, from these curious experiments, the identity of animal heat with the cause of muscular contraction; and still more remarkable, that neither Galvani nor Volta ever suspected the connection of the phenomena with chemical action.

The agency of caloric in exciting convulsions in recently killed fish, was strikingly demonstrated by some

* The experiments were successfully repeated before a committee of the National Institute of France, and afterwards at the Anatomical Theatre in London, Great Windmill Street.

experiments of Mr. Clift, who found that four hours after the head of a carp had been cut off and its heart taken out, (the fish being considered as perfectly dead,) when put in hot water, it leaped out of the vessel with a degree of vigour equal to the struggles of a living fish. M. Dessaignes also observed that convulsions were produced in the frog, when the muscles and nerves were connected by a silver spoon in which lighted charcoal was placed. (*Phil. Transactions* for 1815.)

A similar fact was observed by Lord Bacon, who relates that he saw, with his own eyes, the heart of a criminal taken out of his body some time after execution, and thrown into the fire, when it leaped up several times to a considerable height. Without commenting on these facts, which belong to another portion of the present work, it may be observed that they demonstrate the agency of heat in animal motion, at least as clearly as that of electricity,—even admitting (what has never been proved) that electricity could exist independent of caloric.

The first philosopher who referred the phenomena observed by Sultzer, Galvani and Volta to chemical action, was Fabroni, in a paper communicated to the Academy of Florence, in 1792. He had often observed that fluid mercury retained its lustre for a long time when alone; but that when amalgamated with other metals, it speedily tarnished by oxidation; and that similar effects were produced on some alloys of tin. He had remarked in the Museum of Cortona, inscriptions engraved on plates of pure lead in a perfect state of preservation; while in the Gallery of Flo-

rence, he found that medals composed of lead and tin, or lead and some other metal, were entirely reduced to a white powder, though carefully wrapped up in paper, and preserved from the atmosphere in drawers. He had further noticed, when in England, that the iron nails then employed in fastening together the copper sheathing of ships, caused so much corrosion of the copper, that the holes made by them were sometimes larger than the heads of the nails; all of which he referred to *chemical action produced by the mutual contact of different metals* exposed to moisture, atmospheric air, &c. That this was the case in the experiment of Sultzer, he thought was proved by the fact, that when the tongue was wiped dry, scarcely any perceptible sensation was excited.

In another set of experiments, Fabroni put different metals in vessels filled with water, two and two, in contact, when he found that the most oxidizable metal was visibly oxidized at the moment of contact. A month afterwards, the connected metals had acquired so strong a degree of cohesion as to require a considerable force to separate them. Not only were the metals oxidized, but covered over with small crystals of various forms, which had been deposited from a state of solution. (*Traité de l'Électricité et du Magnétisme*, par M. Becquerel, vol. i. p. 88.)

The above passages are sufficient to show that Fabroni clearly recognized the necessity of chemical action in all galvanic phenomena, and that his views were much more accurate than those of his contemporaries. Still it must be acknowledged that he never explained why two metals in contact oxidize more

rapidly than when isolated; and that no satisfactory account has yet been given of the primary source of galvanic action by his successors; the consequence of which is, that the theory of the pile, like that of universal chemistry, is still involved in obscurity.

This much, however, is certain, that all the different elements of ponderable matter have various degrees of attraction for caloric; and that during all chemical combinations, there is a transition of caloric from one to the other.

When treating of freezing mixtures, it was shown that when chloride of sodium, chloride of calcium, potassa and many other salts are brought in contact with ice, there is a rapid abstraction of caloric from the ice to the salts, by which both are dissolved and chemically united; that when lead, tin and bismuth are brought in contact, they dissolve at a much lower temperature than when isolated, and thus unite chemically into an alloy. For the same reason, many other metals, rocks and gems are rendered more fusible, and combine more readily with each other by the addition of what has been termed a flux. Clay is more fusible when mixed with fluor spar, and quartz with lime, than when separately exposed to the action of heat.

Whatever may be the true explanation of these phenomena, it is evident that caloric is essential to oxidation, solution, and to all chemical combinations, whether of gases and liquids with each other, and with solids; or of solids with each other. It therefore follows, that if chemical action be indispensable to the disengagement of galvanic electricity, caloric must be the primary source of all the resulting phenomena.

Passing over the long and idle controversy between the partisans of Volta, (who maintained that galvanic electricity results from the contact of different bodies, and those of Fabroni, who contend that it is wholly the result of chemical action,) it may be sufficient to state, that the combined researches of nearly all the most distinguished philosophers of modern times demonstrate, that there can be no galvanic action without chemical decomposition.

For a long time it was supposed by Sir H. Davy that contact was necessary to its commencement, and that it was kept up by chemical action. But from the experiments of Wollaston, Gautheraut, De la Rive, Avogadro, Parrot, Becquerel and Faraday, the question may now be regarded as decided. Davy himself observes, in the *Bakerian Lecture*, read before the Royal Society on the 8th of June, 1826, that there is no instance of electro-motion, (by which he meant galvanic action,) without chemical decomposition. He also states, that when oxidizing liquids are employed in maintaining the action of the battery, the more oxidizable metal always afforded positive electricity in relation to a less oxidizable one; that potassium, which is the most oxidizable of all the metals, is positive in relation to all others; and so of its amalgams; that barium and its amalgams are positive in relation to an amalgam of zinc, which is positive in relation to pure zinc, zinc to cadmium, the latter to tin, tin to iron, and iron to bismuth.

Corresponding with the above results are those of De la Rive, who found that the direction of a galvanic

current is not determined by metallic contact, nor by the nature of the metals relatively to each other, but by their chemical relation to the exciting liquid; that of two metals composing a voltaic circle, the one which is most energetically attacked is positive with respect to the other. Thus, when tin and copper are placed in acid solutions, the former, which is most actively corroded, gives a positive current through the liquid to the copper: but if put into a solution of ammonia, which acts most on the copper, the direction of the current is reversed. Copper is positive in relation to lead in nitric acid, which oxidizes the former most rapidly; whereas, in dilute nitric acid, by which the lead is most speedily dissolved, the lead is positive. He found that even two plates of copper, when immersed in solutions of the same acid, but of different strength, form a voltaic circle, the plate on which chemical action is most energetic giving a current of positive electricity to the other; and that a compound circle might be formed solely of zinc plates and one acid, provided the same side of each plate be more rapidly oxidized than the other.

The following experiments are decisive against the theory of Volta. M. De la Rive ascertained that when zinc and copper plates were brought in contact in an atmosphere of hydrogen or nitrogen, wholly deprived of oxygen, moisture and other bodies, no electricity was evolved; and when he purposely increased chemical action by exposing the zinc to acid fumes, or by substituting for zinc a more oxidizable metal, such as potassium, the electrical effects observed, on contact

with copper, were greatly augmented, the amount being in proportion to the chemical action. (*Ann. de Chim. et de Phys.* xxxviii. et ix.)

The above facts have an important bearing on the general theory of electricity, for they seem to prove that what are termed positive and negative electricity are only *plus* and *minus* conditions of one and the same ethereal element; consequently, that the oxygen, chlorine, fluorine, iodine and bromine of acids, salts, &c. are attracted by the minus or negative pole of the battery; and hydrogen, metals and alkalies to the positive pole, because in their natural state these two classes of bodies are combined with different proportions of thermo-electric ether. But as I have before shown, (pp. 193 and 194,) that bodies are neither essentially positive nor negative, but vary according to circumstances, and that those which belong to the electro-positive class unite with each other, as well as with those that belong to the opposite class, it is evident that chemical attraction is not wholly the result of electric polarity, as maintained by Davy.

It has been often said that the energy of the voltaic battery is in proportion to the conducting power of the liquid that acts on the plates. The absurdity of this hypothesis will appear in a striking point of view, when it is remembered, that of all liquids mercury is the best conductor; yet when employed between the plates of a battery, no electricity whatever is disengaged. The simple matter of fact is, that the quantity of electricity evolved is proportional to the rapidity with which the intervening liquid is decomposed by the metallic plates; and that when the chemical

action ceases, the disengagement of electricity also ceases.*

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* From the experiments of Ritter, Davy and others it would appear that two different metals are not requisite to the disengagement of the galvanic fluid, but to its concentration. Sir Humphrey Davy formed galvanic series of a single plate of zinc, one side of which was exposed to an acid, and the other side to water; also by a single metal acted upon one side by an acid, and on the other side by hydro-sulphurets. (*Philosophical Transactions* for 1821.)

It has been further shown by M. Becquerel that electricity is evolved whenever metals are immersed in acid solutions that act chemically on them. The same effect was produced during the combination of acids and alkalies,—when nitrate of iron acts on leaves of platinum foil; or nitro-muriatic acid upon gold; and even on mixing a concentrated acid solution with a diluted solution of the same acid. (*Ann. de Chem. et de Phys.* xxxv. 120.)

From such experiments it has been inferred that electricity is disengaged during all chemical actions. But it is certain that all chemical combinations and decompositions are attended with changes of temperature; that is, by the absorption or evolution of caloric. The disengagement of electricity during the action of the strong acids on metals, alkalies, &c. has been deduced from the fact, that when the two ends of a multiplying wire are made to communicate with the combining bodies, the magnetic needle is deflected, as it is during the passage of a current of voltaic electricity through it. But the same effect is produced when one end of the multiplying wire is made to communicate with melted silver, and the other end with a portion of the same metal in the solid state; or when the two extremities of the multiplier are made to communicate with different parts of other metals when of different temperatures; from which it would appear that the magnetic phenomena are independent of chemical action, and result from the transition of caloric through the multiplying wire, as will be proved further on.

THEORY OF GALVANIC, OR VOLTAIC ELECTRICITY.

On the first introduction of the voltaic pile into Paris, Napoleon was so strongly impressed with its importance, that he offered 60,000 fr. to the individual, of whatever nation, who should make a decided advancement in the knowledge of its theory, as Franklin did in common electricity. Had this extraordinary man devoted himself to the task, it is probable that he would have gained the prize. He proposed several interesting points of inquiry in regard to the theory of its action. He wished that experiments should be made on the pile at very different temperatures, for the purpose of ascertaining whether caloric created any remarkable difference in its power of producing electricity. On witnessing the transport of the elements of salts to its respective poles, he is represented to have said to his physician, Corvisart, "Docteur, voilà l'image de la vie." (*Traité de l'Électr. et du Magnétisme*, vol. i. p. 108, par M. Becquerel.)

It sometimes happens that new discoveries retard the general progress of science for a time, by withdrawing the attention of philosophers from a general and comprehensive survey of nature, to that of some obscure and isolated province.

The brilliant discoveries of Galvani, Volta and Davy directed the inquiries of men to the chemical and physiological properties of electricity, to the neglect of the still more obvious agency of caloric. Had philosophers studied the cause of solution, combustion, fermentation and ordinary decomposition with half the attention

bestowed on electro-chemistry, they would have discovered that caloric is indispensable to the chemical union of oxygen with combustibles; of salts with water; metals with acids, and with each other; in short, that without caloric, there is no chemical attraction.

This would have led them to investigate the relations of caloric and electricity, one of the most important problems in physics, from its intimate relation to the whole constitution of nature. If they be only modifications of one and the same universal principle, we cannot expect fully to comprehend the most simple phenomena of attraction and repulsion, without understanding its general laws.

When treating of chemical solution, it was demonstrated that metals are dissolved by the caloric of the strong acids, and combined chemically with them as certainly as that salts are dissolved by the caloric of water, and thus chemically combined with it.

If then there be not two causes of chemical attraction, it is evident that the same agent which causes sulphuric acid to combine with copper, making a transparent solution of copper, causes the same acid to combine with the plates of the voltaic battery, by which they are oxidized and dissolved, when a portion of the latent caloric of the acid is given out in the concentrated form of electricity, conducted from the plates by the connecting wires, and thence to the extremities of the battery.

I have already shown that sulphuric acid is composed of oxygen, sulphur and caloric; that nitric acid is composed of oxygen, nitrogen and caloric; and so

of other compounds. When solutions of nitric, sulphuric or hydrochloric acids are poured upon metals, there is a rapid transition of caloric from the acids to the metals, by which they are made to combine chemically, with great diminution of volume and evolution of heat. When poured on copper and zinc filings, they are decomposed, and the metals oxidized still more rapidly. But when the same metals are arranged in the form of a galvanic battery, and immersed in the same solutions, electricity is evolved: from which it would seem to follow, that the latent caloric of acids is given out in the form of calorific or electric ether, according to the mode of its disengagement.

Another fact of fundamental importance to a right understanding of the nature of voltaic electricity and its relation to caloric is, that its character is modified by the size and number of plates composing the battery. For example, when it is composed of a few large plates of zinc and copper, an imponderable fluid is evolved, possessing all the properties of highly concentrated caloric,—which fuses and ignites the hardest gems and densest metals submitted to its action; while it is destitute of nearly all the properties by which common electricity is characterized. The largest battery of this description ever constructed, was that of Mr. Children, which was composed of twenty plates of zinc and copper, six feet long, and thirty-two inches broad. When immersed in a strong acid solution, it melted, ignited and fused a large platinum wire, six feet in length; *but communicated little or no shock to the system; would not charge a Leyden jar; produced*

*no sensible effect on the electrometer; and, unlike common electricity, was conducted slowly by metals, minerals, fluids, &c.**

When the battery is composed of two extensive coils of zinc and copper; or of many plates, so arranged as to constitute only a single pair of zinc and copper plates of enormous dimensions, as in Dr. Hare's calorimotors, the calorific effects are still more remarkable.

On the other hand, when the battery is composed of a large number of metallic plates of small size, and immersed in the same solutions, electricity is evolved, which affects the electrometer, communicates a shock, and passes through conductors with the speed of lightning.†

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* The large battery of the Royal Institution, employed by Sir H. Davy, which consisted of 2000 pairs of four-inch plates, melted platinum, quartz, the sapphire, magnesia and lime, like wax, both in vacuo and in the atmosphere; while charcoal, plumbago and the diamond were rapidly dissipated in the form of vapour.

† When the battery is composed of a few large plates and immersed in an acid solution, *caloric* is evolved until the acid is decomposed, or until the metallic plates are consumed. But if the battery be composed of a large number of small plates of the same metals, and immersed in the same acid, *electricity* is produced, until the plates or acid are consumed by oxidation; which demonstrates the identity of caloric and electricity beyond the possibility of a doubt; for it would be a perversion of common sense to suppose, that by merely changing the size and number of the plates, a radically different fluid could be evolved, while the metals and solutions in which they are immersed, are the same. Shall I be asked for clearer proofs that the latent caloric of acids is the basis of electricity? We might as well be asked to prove that the sun

These striking facts led Dr. Hare to suppose that both *caloric* and *electricity* are developed during all galvanic operations; and that they are combined with each other by what he calls "the reciprocal attraction of imponderables." He supposed that when two or more large plates were employed, caloric predominated; but that when a large number of small plates were used, electricity predominated. One thing is certain, that the character of the electricity is modified by every variation in the size and number of the plates composing the battery. But if we suppose that caloric is combined with galvanic electricity, because it fuses and ignites metals or other bodies, we shall be forced to admit that it is also a constituent portion of common electricity, for this fuses and ignites bodies like voltaic electricity. He further supposes, that "electricity fuses and ignites metals, &c., by combining with their latent caloric; thus augmenting its repulsive agency and causing it to overcome their cohesion." But he omits the important fact, that *electricity also increases their temperature, and that its former properties are changed and merged into those of caloric, as it fuses and ignites bodies.*

The unavoidable conclusion from the above facts is, that caloric and electricity are only different forms of

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is the fountain of light and heat; or that rain accompanies lightning.

It is generally known that the most powerful batteries are composed of bodies which act with the greatest energy upon each other, such as zinc, copper and nitric acid; and that such as undergo no chemical changes exhibit no electrical effects, such as gold, silver and water.

the same elementary agent, varied by the numerous modes of its separation from ponderable matter: or, that there are two distinct and universal agents combined with ponderable matter and with each other, "by the reciprocal attraction of imponderables," as maintained by Dr. Hare. It need scarcely be observed, that there has never been the slightest evidence adduced that such an attraction exists between caloric and electricity, admitting them to be distinct fluids; while it is contrary to the simplicity which characterizes all the operations of nature to suppose the existence of two universal agents, endowed with the same fundamental properties. There cannot be two universal principles of action in nature; because if they were different they would interfere with each other and produce discord; and if they were alike they would produce like results, which amounts to the same thing as if they were radically identical.* If every apparent difference between caloric and electricity be taken as an argument against their identity, it would be easy to prove that there are more than one hundred electricities. There is a far greater difference between the voltaic fluid disengaged by Children's battery and that from a common electrical machine, than between the former and the caloric evolved by ordinary combustion; while the deflagration of steel

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* Sir Isaac Newton thought it "inconceivable that two *ethers* could be diffused through all nature, one of which acts upon the other, and by consequence is reacted upon, without retarding, shattering, dispersing and confounding one another's motion. (*Opticks*, p. 339.)

wires in oxygen gas and the detonation of gunpowder, are more like an electric explosion than anything else.

The ordinary process of combustion by which *heat* is evolved, consists in the combination of oxygen with other elements. The galvanic fluid is decomposed by the same process: while it would be contrary to all the rules of a sound induction, to suppose that two or more distinct ethereal agents could be disengaged from the same elements. If we reject this simple mode of reasoning, we shall be compelled to admit the existence of as many electricities as there are modes of separating it from ponderable matter; which would be absurd. It is far more consistent with facts and the harmonious simplicity of nature to suppose that one agent produces all the diversified powers and activities of matter; that it exhibits different properties and appearances under different circumstances, according to its diffusion, concentration, compression, &c.; and to the mode of its combination with different substances, in a solid, liquid, gaseous or imponderable state, as in the matter of light.

We have already seen, that a certain temperature is indispensable to combustion, fermentation, putrefaction and to every process of oxidation, however slow, as the rusting of metals; that when atmospheric oxygen is thus made to combine with metals, its volume is diminished, and a portion of its latent caloric liberated, in the form of radiant ether, by which the process of oxidation is kept up. I have also proved, that when metals are exposed to the action of strong acids, there is a transition of caloric from the acids to the metals, by which the latter are dissolved and chemi-

cally combined with the menstruum; that caloric is the cause of all attraction between fluids and solids; that the solvent power of water, acids, &c. is greatly augmented by heat; and that when metals are dissolved in the strong acids, caloric is given out in great abundance, as in ordinary combustion. So nearly does the operation of a voltaic battery resemble combustion, that more or less heat is always disengaged by its action. When the acid solution is strong, and chemical action energetic, the whole apparatus becomes warm; viz., a portion of the latent caloric of the acid is conducted from the plates to the connecting wire in the form of electricity; while another portion is liberated in the diffused form of sensible heat, as when water and acids are poured upon quick-lime.

That the caloric of liquids is the cause of their chemical action on the plates of the battery, is proved by the fact, that when the apparatus is supplied with *hot* solutions of the strong acids, its energy is greatly augmented, and the metallic plates rapidly dissolved; in other words, the battery is very soon burned out.

It is stated by Singer, Donné and others, that the energy of De Luc and Zamboni's columns* is greatly augmented by an elevated temperature, and diminished by a reduction of temperature; that they are more active during summer than winter: and in a warm than a cold room. Dr. Jaegar found, that after

* The first is formed of disks of writing-paper, interposed between thin leaves of zinc and silver; while that of Zamboni was composed of paper disks gilt or silvered on one side, and the other side covered with a layer of black oxide of manganese mixed with honey.

the dry pile had lost its energy, it was restored by a temperature of from 104° to 140° F. That the energy of this pile is owing to chemical action, like every other form of the battery, is proved by the oxidation which it undergoes, and by the total loss of its power when perfectly dry.

When isolated plates of zinc and copper are immersed in dilute nitric acid, they are oxidized and dissolved, when caloric is liberated as during combustion; but when they are connected by means of a metallic wire, galvanic electricity is evolved. There can scarcely be a doubt that if the caloric evolved by ordinary combustion could be concentrated and conducted off like the galvanic fluid, it would exhibit electrical phenomena. Pouillet has actually shown that electricity is disengaged during nearly all combustions, though in a slight degree, as had been proved long ago by Lavoisier and Laplace, De Saussure, and by Mr. Read. Were it not for the caloric contained in nitric acid, it would not dissolve zinc and copper filings. For the same reason, it would not combine with the plates of the battery; nor would it enter into chemical combination with any other substances. The battery owes all its energy to chemical action, as certainly as that combustion is a chemical action. Can common sense admit that caloric causes atmospheric oxygen to combine with combustibles, and that some other agent causes the oxygen of acids to combine with the plates of a voltaic battery? The supposition is wholly unphilosophical, and is contradicted by all the analogies of nature. Combustion is a chemical process to all intents and purposes, and is produced by the same

agent which causes all other chemical actions. Another important general fact, showing the intimate relation between combustion and galvanic action, is, that the action of the pile, like that of combustion, is far more energetic in oxygen gas than in atmospheric air; and ceases *in vacuo*, in nitrogen, and other gases that do not act chemically on it.

If we compare the effects of galvanic electricity with those of caloric evolved by ordinary combustion, we find that they are the same. When voltaic electricity fuses, ignites and volatilizes metals, gems and all other combustibles, does it not produce the same effect as that of an oxy-hydrogen blow-pipe, or the concentrated heat of a forge? and if it produce the same effects, must it not be the same agent? Can electricity render bodies hot, and yet not be an igneous fluid? When charcoal is submitted to the action of a galvanic current under water, it is ignited, and decomposes the water as when heated by ordinary combustion: and if an iron wire, connecting the extremities of a battery in action, be made to pass through water, the latter becomes hot and boils. When the wire is thus heated, it attracts oxygen from water, as when rendered red hot by other means. Like caloric, electricity causes oxygen and hydrogen to combine to form water, and again causes its decomposition.

If then it be an established axiom in philosophy, that the same effects should be ascribed to the same cause, caloric and electricity must be essentially the same agent.

The recent experiments of Dr. Faraday have fur-

nished many important facts, which show the intimate relation between combustion and the evolution of electricity by galvanic action.

It is very well known, that oxygen is not indispensable to combustion; that during the rapid combination of chlorine, fluorine, iodine, &c. with hydrogen, sulphur, phosphorus and the metals, caloric is evolved in the form of radiant heat, as in ordinary combustion; in short, that caloric is evolved during nearly all rapid chemical combinations. By following up the experiments of Sir H. Davy, Dr. Faraday has shown, that when chlorides, iodides, fluorides, oxides, cyanides, nitrate of potassa, chlorate of potassa, sulphate of soda and various other compounds were fused by heat, and interposed between the plates of copper and platinum of a voltaic battery, electricity was evolved as when acids were employed; and in some cases much more freely. He adds, "there are hundreds of bodies which evolve electricity in the same manner, when in a state of fusion; but that when they become solid, the decomposition and the electric currents cease." He thinks that solidification prevents decomposition, &c. "merely by chaining the particles to their places, under the influence of aggregation." (*Experimental Researches in Electricity*, 4th series.) Had this distinguished experimenter recognized the agent by which particles are aggregated and chained together, he would have found that it is the *alpha* and *omega* of chemical action, without which there could be no voltaic electricity; and that it is the source of all electro-chemical combinations and decompositions.

But there are certain minute philosophers, who maintain that the *slightest difference between any two agents* destroys their identity. If such objections to the unity of caloric and electricity were well founded, we should be compelled to admit the existence of more than a hundred species of electricity; for it differs with every modification of the process by which it is produced, from thermo-electricity of the lowest tension to the fluid of a Leyden battery, which darts through metals and the living body with the speed of lightning.

It is known, that the different forms of voltaic electricity pass with different degrees of velocity through the same conductors; and that in this respect there is an almost infinite variety in the properties which it presents. Yet these differences have not prevented Wollaston, Faraday and many of the most distinguished philosophers of the continent, from maintaining the identity of electricity under every variety of form and appearance which it exhibits, from that of Children's battery to De Luc and Zamboni's pile; and from a flash of lightning to the magnetic spark, or the shock of a torpedo. Surely there is a far greater difference between the electricity developed by a common machine and Children's battery, than between the latter and solar heat concentrated by means of a large burning-glass. It was shown by Mr. Parker of Fleet Street, that the most intense heat of a burning-glass three feet in diameter, though sufficient to fuse and volatilize gems and metals in a few seconds, passed through water without heating it like electricity; and that when it was made to strike upon the finger, it

produced little or no sensation of heat, but that of a sharp cutting instrument.

ANALOGIES BETWEEN VOLTAIC ACTION AND SUBTERRANEAN CHEMICAL FORCES.

From a general view of the foregoing facts and observations, it would appear that the galvanic or voltaic pile affords a miniature representation of nearly all the chemical changes perpetually going on throughout nature; while it exhibits the relations of caloric and electricity, in all their multiform states, in the most instructive manner. There is a striking resemblance between the phenomena of galvanic heat and that developed by volcanic agency; not only in the chemical mode of their production, but in the effects they afterwards exhibit. In both cases the radiating power of the igneous ether evolved is exceedingly small, compared with its power of fusing rocks, metals, gems, &c., while they are both attended with thermotic and electrical phenomena. A large voltaic battery, capable of producing a current sufficiently powerful to fuse and ignite the most obdurate bodies, excites no sensation of warmth beyond the apparatus. It is stated by Mr. Scrope, on the authority of Dolomieu, corroborated by his own observations, that very little heat is radiated from a mass of red-hot lava; that at the distance of a few feet, the thermometer is scarcely affected by it, which induced Dolomieu to suppose that its fluidity was due to some other cause than caloric. (*Scrope on Volcanos*, p. 20.)

The reason why incandescent lava does not radiate

heat like coal, wood, &c. when in a state of ignition, is doubtless owing chiefly to the greater attraction of caloric for metallic and rocky masses, than for combinations of animal and vegetable matter, as explained under the head of radiation.

It has been long known, that the most intense electrical phenomena are displayed during volcanic eruptions. If it be inquired why persons near to a mass of incandescent lava experience no electric shock, it may be answered, that no shock is received from a voltaic battery of large plates; nor should we be able to discover that any electricity was evolved, were it not conducted off by the connecting wires to the extremities of the pile: even then, it exhibits chiefly the phenomena of concentrated caloric, and but slight indications of electricity.

Mr. Scrope has given a highly graphic description of the electrical action that accompanied an eruption of Vesuvius that he witnessed in October, 1822; and which resembled the awful displays of lightning that attended its eruption in 79, when Pompeii and Herculaneum were overwhelmed with lava; and by which the elder Pliny lost his life. "From every part of the immense cloud of ashes that hung suspended over the mountain, flashes of forked lightning darted continually. They proceeded in greatest number from the edges of the cloud. They did not consist, as in the case of a thunder-storm, of a single zigzag streak of light, but a great many coruscations of this kind appeared suddenly darting in every direction, from a central point, forming a group of brilliant rays, resembling the thunder-bolts placed by the ancient artists in

the hands of the cloud-compelling Jove." (*Scrope on Volcanos*, p. 81.)

It is also related by Sir William Hamilton, that the eruptions of Vesuvius in 1767, 1779 and 1793, were attended with the most tremendous exhibitions of lightning; and the two latter with extremely loud explosions of thunder. Zigzag lightning darted incessantly from the enormous black clouds that hung over the crater, resembling in all respects that of ordinary thunder-storms; and accompanied by heavy showers of rain, with whirlwinds, like those which attend water-spouts. Sometimes balls of fire issued from the black cloud, which burst into serpentine streams of fire. He thought that the violence of the subterranean action might be known from the height to which the vapour and smoke ascended, and by the amount of *ferilli*, or volcanic lightning. (*Philosophical Transactions of the Royal Society* for 1795.)

Dr. Daubeny further relates, on the authority of M. Monticelli and other persons who witnessed the eruption of Vesuvius in August, 1834, that from a current of lava which overwhelmed one hundred and fifty houses, and covered about five hundred acres of ground, there arose a black cloud, from which emanated very vivid flashes of lightning, sometimes followed by thunder, but not always. (*Philosophical Transactions*, 1835.)

It is also related in the *American Journal of Science*, that on the 20th of January, 1835, Nicaragua, in Central America, was visited by a tremendous earthquake, and followed by an eruption of the volcano of Cosiguina, by which the atmosphere was filled to a great height and distance with phosphoric sand, smoke and

vapour,—from which issued perpetual flashes of lightning throughout the night of the 20th and the whole of the next day. On the 23d, toward morning, tremendous loud thunder-claps were heard in succession, like the firing of the largest cannon,—from which it was supposed by the inhabitants at the Port of Balize, on the Bay of Honduras, that a naval action was going on, or that a ship was in distress. It is stated that during this earthquake the country was convulsed for more than a thousand miles.

It is here worthy of special notice, that nearly all the volcanos of our planet that are situated on dry land, amounting to about two hundred, have been found in the vicinity of the ocean; while it is probable, from the vast number of the volcanic islands, that there are at least three times as many beneath the sea.

It is well known to modern geologists that submarine eruptions are exceedingly frequent. On the 12th of June, 1811, immense volumes of smoke were observed to arise from the sea, near the island of St. Michael, one of the Azores, by Captain Tillard of the Sabrina; from which issued at intervals, for several days, the most vivid flashes of lightning, and sometimes a continual blaze. During these eruptions an island was formed, about a mile in circumference and two hundred and eighty feet high, which Captain Tillard visited, in company with several of his officers, on the 4th of July, when he named it Sabrina, after his ship. By the middle of October it had disappeared, leaving a dangerous shoal.

During an earthquake on the 9th of July, 1757, eighteen small islands emerged from the sea, near the northwest corner of St. George, another of the Azores; which also disappeared in a few months.

The destruction of the town of Conception, in Chili, by an immense wave of the sea, twenty-eight feet in height, which rolled over it, must have been caused by a submarine volcano, as we are informed by Mr. Caldcleugh that two eruptions of dense smoke were observed to issue from the sea, with violent ebullition, and the evolution of large quantities of gas.

About the same time, flame and smoke burst from the sea, near the island of Juan Fernandez, over which the waves rolled to a great height, as at Conception. (*Phil. Trans.* 1835.) And we learn from the captain of an English ship from the Mediterranean, that on the 18th of May, 1845, in lat. 36° 40′, and long. 13° 44′, immense balls of fire were seen to issue from the sea. (New York *Sun*, July 22, 1845.)

But to return; it has been shown that the voltaic fluid, whether thermal or electrical, is disengaged from nearly all bodies when in a liquid state—from water, acids, saline solutions,—from oxides, chlorides, iodides, &c. when in a state of fusion, during their chemical decomposition by the plates of a battery. The resemblance of this process to that of subterranean chemical action is somewhat remarkable. For example, the products of volcanic eruptions render it almost certain that subterranean caloric is disengaged from *sea water*, which finds its way to the interior through fissures and submarine craters,—where its oxygen combines with sulphur, metals, &c. as the oxygen of acids unites

with the plates of a common battery.* That volcanos are in some way abundantly supplied with sea water, is evident from the vast quantities of steam discharged during their eruptions, which contains chloride of sodium, hydrochloric acid, chlorides of copper, iron, &c. as well as from their geographical positions near the sea. In short, the earth may be regarded as a huge galvanic pile, kept in a state of perpetual subterranean chemical action by the waters of the ocean, as our little batteries are maintained in action by various solutions.

When the plates of a common battery are completely oxidized, chemical action ceases: so when all the materials within a given range of subterranean territory become saturated with oxygen, sulphur, chlorine, &c. chemical action ceases, and the volcanic forces become quiescent, to be renewed elsewhere for indefinite periods of time, until exhausted or burned out like the plates of a voltaic battery.

In North America they have been nearly extinct since the elevation of the Rocky and Alleghany Mountains above the ancient sea that once covered the northern hemisphere; while in South America, and

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* The hydrogen of water may unite with sulphur, making sulphuretted hydrogen; while the union of oxygen with sulphur makes sulphurous acid, which combines with lime, and drives off carbonic acid, a common product of hot springs and volcanos. The nitrogen of atmospheric air, which is admitted through craters, and is mixed in greater or less quantity with all water, combines with hydrogen, forming ammonia. In fine, there is no limit to the play of affinities that take place in this grand laboratory, under the agency of so intense a heat.

on the eastern continent, volcanos are numerous, but confined chiefly to the borders of the ocean. The only feeble remains of subterranean chemical action in North America are its warm springs, which convey off whatever heat is generated below the surface, in a tranquil manner.

The same observations apply to the greater part of Europe and Asia. The Alps, the Apennines, the Himalayas and many other mountain ranges of the old world, afford no evidence of existing subterranean combustion, except the numerous warm springs that issue from their sides. Were it not for this continual discharge of heat, it is probable that they might still be convulsed at long intervals by volcanic explosions, or by earthquakes, which are owing to the confinement of volcanic steam by superincumbent pressure. Warm springs may therefore be regarded as "safety-valves of the globe" still more emphatically than volcanos. It is very well known that when the great geyser of Iceland is obstructed by throwing stones into its funnel, its temperature rises rapidly, which is soon followed by eruptions of steam and water to a great height. It is equally certain, that if the obstruction were equal to the pressure of two or three thousand feet of rocks or lava, earthquakes would follow.

It was before stated that the rapidity with which acid, alkaline and other solutions are decomposed by the plates of the battery, is augmented by increasing their temperature,—that the amount of chemical action, like that of evaporation and rain, is greatest on the surface of the earth within the tropics, *cæteris*

paribus, and diminishes as we approach the regions of perpetual frost.

The same thing would seem to be true of subterranean chemical action, which points out the agency of solar heat in the production of volcanos, and connects the whole theory of geological dynamics with that of solution, combustion and of universal chemistry. It is a remarkable fact, which has never been explained by geologists, that the highest mountains of the earth are within the torrid zone, where they rise to an elevation of from four to five miles above the ocean level; while in the middle latitudes they do not exceed the height of fifteen or sixteen thousand feet; and seldom more than five or six thousand feet beyond the polar circles, although they are nearer to the centre of the globe than any other part of its surface. The islands of the Pacific and Atlantic oceans are also far more numerous within the tropical than the higher latitudes; while it is certain that nearly all of them have been elevated by submarine volcanos.

All the chemical and geological operations of our planet would seem to be in proportion to the energy of solar radiation. Within the tropical regions, the aggregate quantity of earthy and metallic matter conveyed from the interior of the earth in a state of chemical solution by springs, is immense. The amount of evaporation and rain being great, the rivers are large, and rapidly destroy rocks, hills and mountains by mechanical agency; these are transported to lakes and seas, which are rapidly filled up by fluviatile deposits of sand, gravel, clay, pebbles, boulders, &c. forming new lands. The waters of the ocean that find

their way to the interior are warm, and rapidly oxidize its metals and other minerals, by which a corresponding amount of heat is disengaged.

Thus it is evident that all the phenomena of meteorology, chemistry and geology are resolvable into the agency of caloric, or thermo-electric power. If rocks and hills are dissolved by running water, and transported to lakes and seas, caloric is the universal solvent. And here must end forever the long and idle controversy between the Plutonian and Neptunian geologists. If caloric be indispensable to fluidity and solution, it is as necessary to the formation of sedimentary rocks as to the generation of granite, basalt and other volcanic products, which are composed chiefly of metallic oxides, such as those of silicium, calcium, aluminum, iron, potassium and sodium, the oxygen of which is derived mostly from sea water.

There is something great and sublime in the simplicity of the idea, that the same familiar power which "warms in the sun," and clothes the world with enchanting beauty, raises mountains from the ocean, and keeps the whole stupendous fabric of the universe in a state of perpetual motion and circulation.

It was supposed by some of the older geologists that in the earlier periods of the world there were no volcanos—by others, that they were far more active than at present—while Descartes, Leibnitz, Buffon, Fourier and a multitude of more modern philosophers, have maintained that the earth originally existed in a state of fusion or incandescence throughout; and that it has been gradually cooling down ever since. To those who believe in the uniformity of nature's laws, it is needless to

insist that none of these opinions have any foundation in fact; and that they are discountenanced by all analogy. We are rather authorized to believe that the amount of chemical action going on throughout the earth is the same in all given periods of time, and in proportion to the amount of matter. But if volcanic agency were due to a central fire, it is difficult to comprehend why the tropical mountains should be from four to five times higher than those of the polar regions,—why volcanos are confined chiefly to the vicinity of the ocean,—why they should discharge enormous quantities of steam saturated with muriatic salts,—why they should continue in action at intervals for unknown periods of time, and then become extinct,—why volcanic islands are more numerous in the tropical than higher latitudes,—and why hot springs should not be equally distributed all over the earth.

The facts collected by M. Cordier and others, proving that the temperature of the earth increases as we descend below the surface, have been regarded by many geologists as conclusive evidence that earthquakes and volcanos are caused by a central fire. It is true, that in many parts of the world, the temperature of rocky strata and of the water that issues from them is higher at the bottom of deep mines than at the surface, varying greatly however in different places. Humboldt says, that the bore at Mew Salaweak, Minden, in Prussia, is 2094½ Prussian feet. and the temperature of the water 90° F.; which gives a rise of 1·6° for 97·6 feet English. From which he infers, that at the depth of 40,000 feet, the tem-

perature would be 435° F. Mr. Fox found that in the Dalcoath copper mine, in Cornwall, at the depth of two hundred and thirty fathoms, or 1380 feet, a thermometer placed in a hole in the rock, stood at 76° F., and at 82° in water, ten fathoms deeper; the mean annual temperature of the surface being 50°. But the same gentleman states that about two million gallons of water are daily pumped from the Poldice mine, at the temperature of from 90° to 100°; while the mine is only one hundred and seventy-six fathoms (or 1056 feet) deep. It is therefore evident that the temperature is not proportional to depth.

On the other hand, when we reflect that water is continually acting upon the metals, causing their oxidation, and that chemical action is the grand process by which latent heat is disengaged, we need be at no loss to account for its accumulation at great depths beneath the surface, where metals are abundant.

It is impossible to know with certainty how far the waters of the ocean penetrate beneath the surface—probably not beyond the depth of a few miles; nor is there any good reason to suppose that there is much chemical action at greater depths, owing to the superincumbent pressure; while it is known that on the surface of the earth there is very little chemical action without moisture. This much however is certain, that so far as we can trace back the history of our planet, it has been composed as at present, of mountains and valleys, seas and plains, and stocked with plants and animals that have successively arisen and passed away, leaving their fossil remains as a record of their former existence. We have the most

indubitable proofs, that our mountains of granite, gneiss, basalt, &c. were formed during long geological epochs, by successive volcanic movements, and contemporaneous with the deposition of our stratified rocks; while there is not the slightest evidence that the earth was ever in a state of liquid fusion throughout. According to the estimate of Mr. Lyell, there are about two thousand volcanic eruptions every century, which in six thousand years would make one hundred and twenty thousand.

If then it be admitted, that an equal amount of caloric is removed by thousands of hot springs, it is evident that such an enormous loss, if not compensated by the waters of the ocean, (which receive their temperature from the sun,) would cause a sensible diminution of the internal heat of the globe, and consequently, of its volume. But it is acknowledged by Fourier, Laplace and Arago, that the temperature of the earth has not varied the one three-hundredth of a degree in two thousand years. This conclusion was deduced from the fact, that the length of the day has not diminished perceptibly since the time of Anaxagoras, which, it is maintained, must have been the case, had any diminution of the earth's volume taken place.

With the exception of Mr. Lyell and Dr. Daubeny, nearly all geologists of the present day have embraced the hypothesis of a central fire,—maintaining that the superficial crust of the earth is supported by a mass of incandescent lava. Baron Fourier *supposed*, (for he certainly never proved it,) that the earth was originally projected in a state of fusion or of incan-

descence into the planetary space,—the temperature of which he estimates at about —58° F., due to radiation from the sun and fixed stars.

By a long and laborious series of mathematical investigation, he arrived at the conclusion "that the earth, once heated to any temperature whatever, and thus plunged into a colder medium than itself, would cool no more in 1,280,000 years, than a globe of a foot in diameter composed of the like materials, and placed in the same circumstances would in a second of time, —that is to say, in this immense time, no appreciable variation would take place." (*Ann. de Chim. et de Phys.* October, 1834.

The absurdity of supposing that "all the caloric of the earth below the *invariable stratum* (which does not extend much beyond one hundred feet below the surface) comes from a central fire," is too obvious to require a serious refutation.

If there have been two thousand volcanic eruptions every century, according to the estimate of Mr. Lyell, it would give 25,600,000 eruptions in 1,280,000 years: yet the temperature of the globe has not sensibly diminished in that time according to the estimate of Fourier. But if 25,600,000 volcanic eruptions, together with several hundred thousand times as many hot springs, had proceeded from a central fire, the reduction of the earth's temperature must have been enormous. It is therefore evident, that the whole theory is not only hypothetical, but incompetent to explain the phenomena.

There is nothing so remarkable in the natural history of our planet, as the great revolutions of climate

and organic life which it has undergone during the countless ages of the past. The most fertile imagination never conceived anything so wonderful as the varied scenes which the surface of the earth has exhibited during different epochs, before it was inhabited by man or any of the higher orders of animals. The rationale of these mutations is by far the most comprehensive and important problem in geology; for it involves the whole theory of organic life, and its immediate relation to the vast science of physical astronomy. The leading facts hitherto discovered may be reduced to the following general propositions:—

1. That throughout the northern hemisphere, from the shores of the Mediterranean to the north of Europe and Asia, and from the southern United States to Melville Island, in lat. 75 N., the secondary formations are filled with the fossil remains of plants and animals, which could have existed only in an uniformly warm climate, analogous to that of our present tropics.

2. That at different epochs, the land and sea were inhabited by totally different orders, genera and species of organized beings, which successively arose, flourished for a time and then gradually passed away, leaving only their petrified remains as a lasting record of their existence. A similar doctrine seems to have prevailed among the ancient Persians, who maintained that "the earth had been seven times replenished with beings different from man, and seven times depopulated," as we are informed by the Rev. Mr. Faber. (*Pagan Idolatry*, vol. i.)

3. That the more ancient the formations, the more simple are the organisms they contain, and the more

unlike any which now inhabit the earth,*—until we arrive at the newer secondary, in which have been found a few birds and marsupial remains.

4. That during the uniformly elevated temperature which prevailed in the middle and higher latitudes, there was a corresponding uniformity in the zoological and botanical character of the earth, from the equator to the polar regions.†

* For example, from the commencement of the transition to the termination of the coal formation, (supposed to represent three subdivisions or geological epochs,) the sea everywhere abounded with encrinites, polypi, terebratulæ, trilobites, orthoceratites and other testacea, with a few species of strange fishes, which seem to have been the only vertebrated animals then existing. But all of these passed away, (unless we suppose, what has not yet been proved, that they underwent a gradual change under the influence of a different climatic condition of the earth,) and gave place to animals wholly different from any that have existed since the newer secondary eras, such as the huge icthyosauri, plesiosauri, pterodactyli, turtles and other reptiles. As we advance toward the present epoch, we find in the older tertiary formation, the palæotherium, the anoplotherium and remains of cetacea resembling the manati. These also passed away, and were succeeded by a still greater variety of warm-blooded animals, some of which are represented by living species; such as the elephant, rhinoceros, hippopotamus, fragments of the ape and several species of the feline genus; to which may be added the dinotherium, the megatherium, the gigantic mastodon and the elasmotherium, (a strange quadruped resembling both the horse and rhinoceros,) all of which belonged to the newer tertiary epoch, and which have also long since been numbered with the myriads of extinct animals.

† For example, nearly all the fossil plants hitherto discovered in the older formations consisted of ferns, coniferæ, equisetaceæ and cycadeæ; which in all, comprised only about five hundred species, that presented very little diversity of form. It is even asserted by the most intelligent botanists who have carefully examined

In his recent excellent work on geology, Mr. Lyell refers all the past revolutions of organic life to changes of climate, and the latter to geological causes alone; such as the gradual shifting of sea and land, brought about by the agency of volcanos, earthquakes, hot springs, currents and waves of the ocean, the corroding action of rains, rivers, springs and chemical decomposition. But if we admit with Mr. Lyell, that the greater part of the dry land now scattered over the northern hemisphere, may have been formerly confined within the tropics, and the mean temperature of the whole earth thus elevated 20° or 30°, as he maintains, it is still evident, that the polar regions would be excluded from the sun several months in the year, during which time all vegetation would be arrested. Dr. Lindley observes, that "in the present condition of the earth's axis, the polar regions must have been always several months in the year exposed to darkness; a condition in which no plants can exist." Yet the

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the subject, that for a long period, during which the climate of the middle latitudes seems to have exceeded the present temperature of the tropics, cycadeæ alone formed about one-third of the entire Flora; whereas they now constitute only one two-thousandth of the whole. But in the present diversified condition of the earth, as regards temperature, it contains about one hundred thousand species of plants, and above five hundred thousand species of animals. It would therefore appear that diversity in the generic and specific character of organized bodies, depends chiefly on varieties of climate and season, which differ in all the higher latitudes, and owing to the influence of local causes, are scarcely ever exactly alike, even in the same latitudes, as will be shown in the first chapter of book v. This subject opens a vast field of inquiry to those physiologists who may be disposed to investigate the origin of organic species.

older formations around Baffins Bay abound with tropical plants in the fossil state. (*Fossil Flora, preface*, p. xxi.) It is therefore evident, that such a climatic condition of the earth would be wholly incompatible with the existence of a tropical vegetation, which is known to require a mean temperature of about 80° throughout the year.

Among all the causes which modify the temperature of our planet, the most influential by far is the obliquity of the earth's axis. In reality, this condition determines chiefly the vast difference between the climate of the tropical, temperate and frigid zones, together with all the varieties of season. The question therefore naturally arises, whether all the great changes of climate which the earth has undergone, may not have been owing to modifications of the same cause, such as variations in the inclination of its axis, or even a gradual transposition of the equator and poles? In support of this natural view of the subject, it may be observed, that the successive generation and extinction of tropical plants and animals in the higher latitudes, would seem to require the repeated occurrence of such astronomical changes, which, in their turn, afford a complete explanation of all the phenomena. And that such changes are not inconsistent with the laws of nature is evident from the various degrees of inclination in the axis of different planets. Some astronomers have maintained, that the axis of Venus is inclined to her orbit 75°. Should this be actually verified by future observations it will follow, that her polar circle extends into the tropics, within 15° of the equator, and that her tropics extend to the

frigid zone, within 15° of the poles, so as to cause the annual extremes of winter and summer from the tropical to the polar regions.

It has been often asserted by writers on astronomy, that great changes in the planetary inclinations would be inconsistent with the *stability of the system*,—as if all the operations of the universe were not maintained by unceasing changes and revolutions. But, as Mr. Whewell observes, "the cause of perturbation has the whole extent of time to work in," there is reason to believe, that in the progress of long astronomical cycles, every part of the earth has successively been exposed to a vertical sun, and that such changes are absolutely essential to the conservation of the system in its existing state. For if the equatorial protuberance of the planets be owing to the greater amount of light which falls upon the tropics than upon the higher latitudes, it is obvious that they would in time lose their present spherical forms, by which their rotary motions would be deranged,—unless prevented by a gradual transposition of the equator to higher latitudes, or even to the polar circles. And that such a transposition has actually taken place, is strongly corroborated by the high and uniform temperature which prevailed throughout the middle and higher latitudes of the northern hemisphere when it was the abode of tropical plants and animals.

Nor is it less obvious, that if the inclination of the earth's axis should go on augmenting from 0° to 40°, there would be such a general refrigeration, as would destroy nearly all the pre-existing organisms of the middle latitudes,—when the mountain valleys would

be filled with ice, perhaps to the level of the sea, as in Greenland, Spitzbergen and the southern polar continent. In short, there would be what has been called the *Glacial Period* by Dr. Louis Agassiz, who has traced the evident marks of moving glaciers on the polished and scoriated rocks of Switzerland, the Tyrol, Germany, Scotland, Ireland, England and France. And they have since been observed in the United States.*

If we extend our view to the solar system, we perceive that floods of ethereal matter, in the form of light, are perpetually flowing from the sun, and keeping the air, the ocean and the earth, in a state of unceasing circulation—converting solids into liquids, gases and vapours, which are successively changed into plants and animals. The atmosphere is continually wasted by oxidation, combustion and the respiration of animals. But is it not as constantly repro-

* I cannot, however, agree with M. Agassiz, that during what he calls the *glacial period*, the whole surface of the earth presented a vast field of ice, from which projected only the highest mountain ridges; nor that a cold by which every living being was benumbed, *suddenly* appeared, and destroyed the myriads of organisms which but a *moment* before had been enjoying existence; because it is impossible to account for such "a catastrophe" in accordance with any of the known laws of nature. For example, whence came all the waters required to produce a field of ice many thousand feet in thickness? And what had become of the heating power of the sun, when the earth was seized with that *sudden fit* of the ague? Yet there is ample proof, that immediately antecedent to the existing order of things, a climate of polar severity prevailed throughout the middle latitudes of the northern hemisphere, and quite sufficient to destroy nearly all the pre-existing orders of tropical plants and animals.

duced by vegetable and animal decomposition? and are we not authorized to conclude, that if the whole atmosphere were annihilated, it would be again reproduced? or that if all the waters of the ocean were extinguished, they would be gradually regenerated by igneous chemical agency? Wherever there is chemical action there must be liquids and gases generated.* During respiration and putrefaction carbonic acid is generated, the appropriate food of living vegetation, which returns a portion of oxygen to the atmosphere under the influence of solar light. During the decomposition of organic matter, a portion of atmospheric oxygen combines with its hydrogen, forming water,—and so on through all the endless ramifications of nature, we perceive that death is only a transformation of matter, by which the earth is perpetually renovated, and crowned with immortal beauty.

* Hence the improbability of the astronomical hypothesis, that the moon, Vesta and some other planets, have no atmospheres; or that the atmosphere of Ceres is more than 668 miles high, and that of Pallas 465 miles, according to the observations of Schröeter and others.

CHAPTER V.

HYPOTHESIS OF TWO ELECTRIC FLUIDS.

Is the electric fluid one and the same in all bodies? or is it a compound fluid? Each of these hypotheses has been zealously maintained since the time of Dufay and Franklin. But the controversy has consisted rather in pointing out frivolous distinctions in the phenomena produced, than in tracing the fundamental laws by which they are governed. After a patient examination of the facts adduced by the British and continental philosophers, I have not been able to discover any decisive evidence that there are two electricities. On the contrary, it might as well be maintained that there are fifty, or an indefinite number; for this protean agent exhibits an endless diversity of appearances and effects under different circumstances, according to the various bodies from which it is obtained, the mode of its development, &c.

It was discovered by Dufay, about a century ago, that when glass, rock crystal, diamond, precious stones and many other substances, were warmed and rubbed with silk or woollen cloth, they repelled light bodies in their vicinity; but that when resinous bodies were made electric by friction in the same manner, they attracted light bodies which had been electrified by

excited glass. Having caused a piece of gold leaf to be repelled, and suspended in the air by an electrified glass tube, and meaning to chase it about the room by a stick of excited gum copal, he found that, instead of being repelled by it as it was by the glass tube, it was eagerly attracted. From which he concluded that *there were two kinds of electricity, residing in two different classes of bodies; one of which he termed vitreous, and the other resinous,—and that bodies charged with either kind repel bodies charged with the same kind, but attract bodies charged with the other kind.* But when it was afterwards discovered by Dufay, that all bodies acquired the power of attracting and repelling the same substances, according to the manner in which they were electrified, he frankly acknowledged that vitreous and resinous electricity were only different degrees of one and the same fluid. (*Priestley's Hist. of Electricity*, pp. 43 and 412.) Yet the doctrine of two electricities has been constantly imputed to Dufay by nearly all writers on the subject for the last seventy years.*

It is said by those who still maintain the doctrine of two fluids, that if the gold leaves of an electrometer are made to diverge by means of an electrified stick of resin, they will collapse on the approach of an ex-

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* It is related by Van Marum, that the doctrine of two electric fluids became general in France from the fact, that M. Hāuy was ordered by Napoleon to prepare a treatise on natural philosophy for the use of the Polytechnic School, and not having time for reflection, he hastily adopted Coulomb's version of the two fluids. Well might Count Oxenstiern say to his son, "Come and see with how little wisdom the world is governed!"

cited glass tube; when all signs of electricity disappear as if annihilated. Nothing could be more fallacious than such experiments; for I have often found, that after the gold leaves were made to diverge by excited glass, they expanded still further on the approach of excited wax, and *vice versa.* The result is evidently modified by the degree of friction employed, and by the quantity of electricity thus disengaged.

It was long since observed by Dr. Watson, that the rubber of a common electrical machine, exhibited the same electricity in all respects as that which had been produced by the friction of sealing-wax, sulphur, rosin, &c., and afterwards by Canton, Franklin, Beccaria and Wilson, that whenever two vitreous bodies were equally electrified they repelled each other, but when unequally, they attracted each other; and that the same was true of resinous bodies. Dr. Franklin also found, that when glass globes were excited by friction, the spark was larger and longer than when a sulphurous globe was used, and made a louder noise; from which he inferred that *the glass contained on its surface more electricity than sulphur;* he therefore denominated that of the glass *plus* or *positive,* and that of the sulphur *negative*—terms which are now in general use. He might have added, that positive electricity gives larger and more divergent brushes of light than negative, on presenting a metallic point to the prime conductor of a machine in action.

It was subsequently ascertained, that whenever two different bodies are rubbed against each other, they are in different states of electricity—that when a glass tube is rubbed with a dry silk handkerchief, the former

is rendered positive and the latter negative; but if an insulated metal be brought near to the glass, the latter becomes negative and the metal positive. Hence it was concluded by Franklin, that during the action of a common machine, electricity is evolved from the rubber, and attracted by the cylinder of glass, from which it is attracted by the prime conductor, and thence to other conducting bodies. When amber and the tourmaline are rubbed together, the latter becomes *plus* or positive in relation to the amber; but when the tourmaline is rubbed against the diamond, it is minus or negative, and the diamond positive—and so of many hundred other bodies.

The above facts are exceedingly important, and are alone sufficient to prove that positive and negative are only different degrees of one and the same fluid, which accumulates in various proportions on different bodies, according to the relative degrees of their attraction for it. There are no two bodies in nature which have the same degrees of attraction for electricity; nor are there any two bodies which exhibit the same electrical state when rubbed against each other. It has even been found that the same bodies exhibit positive or negative electricity according to their colour, or the condition of their surface—that smooth glass is rendered positive by friction with woollen cloth, and negative when made rough by grinding it with emery, all other things being equal.*

* Is not the attraction of rough glass for electricity less than that of smooth glass, for the same reason that caloric escapes more rapidly from rough than from smooth metals? and does it not ac-

It cannot be denied that the electricity of a common machine is derived chiefly from the rubber; for it is well known that its quantity is greatly increased by spreading over the rubber an amalgam of zinc or tin, the oxidation of which supplies electricity freely, as in the action of a voltaic battery; while amalgams of silver and platinum, which do not oxidize at ordinary temperatures, are of no use. But is it not evident, that if the prime conductor receive its electricity from the rubber, that positive and negative are only different proportions of the same fluid?—that it accumulates and becomes plus on the prime conductor, because of its greater attraction for it?†—and that whether positive or negative, its essential properties are the same under all circumstances? Is it not owing to the attraction of metals for electricity, that during the concretion of melted sulphur, chocolate, calomel and glacial phosphoric acid from a state of vapour, in insulated metallic vessels, the latter become electrified plus, and the former minus?

It was before stated, that the more oxidizable metal in the galvanic circle furnishes positive electricity in relation to the less oxidizable one, which is in direct opposition to the theory of two fluids. M. Becquerel

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cumulate upon insulated metals in greater quantities than on electrics for the same reason that the former are good conductors? (See *page* 183.)

† Something analogous takes place during the action of the galvanic pile. When the battery is composed of zinc and silver, and immersed in an acid solution, the zinc is oxidized, by which electricity is disengaged, and passes to the silver, which is rendered positive; while the zinc, like the rubber from which the electricity proceeds, is negative.

regards it as a proof of two galvanic fluids, that positive electricity permeates imperfect conductors more readily than negative. But this is just what might be expected from the *plus* and *minus* conditions of the same agent. In accordance with this view, it has been found that, other things being equal, the heating effect of voltaic electricity is in proportion to its quantity, and that the heating effect of positive electricity exceeds that of negative.

It was maintained by Winterl, Œrsted, Berzelius, and at one time by Davy, that heat and light were produced by the union of positive and negative electricity. After what has been already offered in regard to the relations of caloric and electricity, it would be useless to multiply arguments against so bald an hypothesis. It was afterwards shown by Sir Humphrey Davy himself, that both heat and light are produced by either positive or negative electricity alone, though he adopted the doctrine of two fluids.

The following experiments of De Saussure clearly illustrate the identity of positive and negative, with *plus* and *minus* conditions of the electric fluid. On pouring water into heated iron or copper vessels when insulated, and connected with an electrometer, rapid oxidation was produced, and positive electricity evolved; but after the metal became covered over with a coating of oxide, less electricity was disengaged, which was negative. (*Voyages dans les Alpes*, tome ii. p. 244.)

It is also worthy of special notice, that he procured electricity from the vapour of water without any chemical decomposition—a fact which has been recently

controverted by Pouillet, as before stated, (*page* 292;) that the evaporation of water from heated silver and white porcelain vessels was attended with a disengagement of electricity, that was generally positive, but sometimes negative. The same thing was observed on placing incandescent pure white quartz in water.

The advocates of the theory of two fluids explain the phenomena of electrical attractions in a singularly gratuitous manner. They say that when an electrified glass tube or stick of wax is brought near to light bodies, it communicates to them the opposite electricity from its own; and that they are brought together by the mutual attraction of the two electricities for each other—that when they touch the excited electric, they acquire the same kind of electricity which it has, and consequently are repelled. (*Thomson on Heat and Electricity*, p. 362.) It might as well be said, that liquid metals attract the same metals when solid, because they are in opposite states of electricity; or that the attraction of the living body by frozen mercury is owing to the combination of the former with positive, and the latter with negative electricity; and that the effect is produced by the mutual affinity of the two fluids: whereas I have proved that the attraction of frozen mercury, and other cold metals, for the living body, is in proportion to their affinity for caloric, which is plus in the one, and minus in the other; and that all such phenomena are owing to the attraction of caloric and electricity for ponderable matter.

The whole train of Dr. Thomson's reasoning in favour of two fluids is founded on groundless assump-

tions. 1. *That there is no attraction between electricity and ponderable matter;* 2. *That there is an attraction between positive and negative electricity;* 3. *That matter does not repel matter; and* 4. *That nothing but the pressure of the ambient atmosphere prevents the escape of electricity from bodies.* (*Idem*, p. 424.) Feeling some doubt in regard to the last position, he elsewhere speaks of "the unknown cause which prevents it from leaving them." (*Page* 431.) Dr. Thomson maintains, that "matter does not repel matter, because, in the motions of the heavenly bodies, no such repulsion has ever been observed,"—from which it would seem that he denies the existence of a repulsive agency in nature. Having assumed the above premises, he adds:—"If matter does not repel matter, and if there does not exist any attraction or affinity between electricity and matter, then the Franklinian theory of positive and negative electricity cannot be correct." (*Page* 425, *on Heat and Electricity.*)

In accordance with the hypothesis, that there are two electric fluids which have a mutual attraction for each other, it has been maintained by several writers on natural philosophy, that when a cloud passes over a mountain, or any other portion of the earth, it communicates to the mountain, &c. the opposite electricity from its own, when the two fluids attract each other, producing a discharge of lightning. Such is the mystic jargon of which this great and beautiful science is composed at the present day. The truth is, that, notwithstanding the many new facts which have been discovered within the last thirty-five years, the theory of electricity is far more unintelligible than it was left

by Franklin, Canton, Wilson, Beccaria and Priestley; for they did recognize the important fact, that all the attractions and repulsions produced by electricity are owing to its affinity for common matter, and repulsion of its own particles. Many of its phenomena are yet involved in profound obscurity. We know not why it is, that when an insulated oblong conductor is brought near to an electrified body, the end nearest to it becomes negative, and the opposite end positive, while in the centre there is no sign of electricity. We do not comprehend clearly why the electricity of a large battery, or of an immense mass of aqueous vapour, becomes concentrated into a spark or ball of fire.

If, however, it be true, that all the forms and modifications of this mysterious agent are convertible into caloric, the theory of both will be greatly simplified, and must shortly be reduced to a very few fundamental axioms.

I have proved from the most elaborate series of experiments on record, performed by De Saussure and Read, that all atmospheric electricity, even that of the most serene weather, is disengaged from aqueous vapour; and by the experiments of Dalton, that caloric is the true and only cause of evaporation. There is also a perpetual flux and reflux of the electric fluid, corresponding with the diurnal variations of temperature, and fluctuations of the barometer. According to De Saussure, it diminishes from nine or ten o'clock in the morning until five or six P.M., and increases until eight, when it again decreases until sunrise, when it is almost null; that is, it is most abundant when the vapour of the air is undergoing condensa-

tion, (for the same reason that it is plus or positive during the formation of clouds, and during rain or snow;) but diminishes during the heat of the day, while the vapour of the air is undergoing expansion; by which it is connected with the whole theory of evaporation, condensation and lightning. It is further stated by De Saussure and many others, that atmospheric electricity is constantly changing from positive to negative, which is also quite inconsistent with the hypothesis of two fluids.

It is only by extending our knowledge of nature, that we are enabled to trace an endless diversity of apparently isolated effects to some principle which connects and governs them; or to distinguish an unknown cause from the individual and ever-varying phenomena it produces. The most signal and delightful triumphs of philosophy spring from the perception of analogies that seem remote and obscure, until closely analyzed. From the imperfect outline which has been already presented of this vast and complicated subject, it is obvious that all the operations of nature are so intimately connected, that we cannot make any substantial progress in the discovery of general principles without ascending to the primary source of all physical power.

I have shown that nearly all the most distinguished philosophers, ancient and modern, have recognized the existence of such an agent. It was the Πῦρ καθαρσιον of Hippocrates—the Ψυχὴ of Aristotle,—or the *form of forms*,—by which he meant the cause of causes—the *anima mundi* of the Romans—the *archæus* of Paracelsus and Van Helmont—the *materia subtilis* of Descartes—the *pneumatical power* of Bacon—the *phlogis-*

ton of Beccher and Stahl—the *electric* fluid of Franklin, Priestley and Beccaria—the *latent heat* of Dr. Black—and the *caloric* of modern times.

ANALOGIES OF CALORIC AND ELECTRICITY.

It has been shown throughout the preceding portion of this work, that all the motive powers of caloric are resolvable into the primary and universal law by which *it repels its own particles, and attracts those of ponderable matter, with forces that vary inversely as the squares of the distance.*

The phenomena of electrical attractions and repulsions are clearly resolvable into the same law.

It would be a needless waste of time to bring forward the numerous proofs, that all the forces of attraction and repulsion are inversely as the squares of the distance. It has been demonstrated by Buffon, Laplace, Coulomb and other philosophers, that the power of all emanations, such as light, caloric, and electricity in the diffused state, are subject to the same law, like that of gravity. The ringing of electric bells, the dancing of pith balls under an electrified tumbler, of paper images, and many other similar experiments, performed for the amusement of popular assemblies, are referable to the above law. When light leaves of gold, copper, silver, zinc, &c. are brought near to the wire that connects the extremities of a battery in action, or to insulated metals when electrified by a common machine, they are attracted by them.

When treating of chemical attraction, (book ii. chap. ii.) it was shown that caloric causes oxygen to

combine with all other elements, from the slowest process of oxidation, as in the rusting of metals, fermentation, &c. to the most rapid combustion. Electricity produces the same effects. It was first observed by Dr. Franklin, that when iron or steel wires were submitted to a few electrical shocks, they became covered over with a coating of rust. Dr. Priestley observed the same effect on other metals; after which Cuthbertson proved, by a great variety of experiments, that all the known metals might be rapidly oxidized by common electricity—even gold and platinum, which are difficult to oxidize by the ordinary modes of applying heat.

By the attraction of caloric for ponderable matter, it combines with various solids, produces their fusion, and causes them to cohere with each other. By its repulsion of its own particles, it decomposes oxides, chlorides, iodides, bromides, alloys and all other compounds.

The same is true of electricity, which dissolves and decomposes the most refractory bodies, such as the earths, alkalies, and all other metallic oxides, and again causes their elements to recombine. In short, there is no combination or decomposition which may not be effected by either caloric or electricity, when sufficiently concentrated, and in due proportions.

When treating of cohesion, it was shown that caloric has various degrees of attraction for different bodies; and that their conducting power is in proportion to that attraction,—that the lightest known solids give out large quantities of caloric during combustion, and are bad conductors; while metals and other dense bodies that evolve much less caloric, are good con-

ductors,—and that, other things being equal, the conducting power of metals is augmented in proportion as they are deprived of caloric.

It is also known that the lightest solids, *cœteris paribus*, afford the largest amount of electricity by friction,—and that they are bad conductors of electricity. It was further ascertained by Sir H. Davy, that the conducting power of metals for voltaic electricity is diminished in proportion to the elevation of their temperature, (*Phil. Trans.* 1821;) and I have shown that their cohesion is diminished in the same ratio. It is therefore evident, that the conducting power of bodies for both caloric and electricity is modified by every alteration in the relative proportions of ethereal and ponderable matter of which they are composed; and that as a general rule, with few exceptions, the same bodies are conductors and non-conductors of both.* (See *Theory of Conduction.*)

It may be observed, that no two series of experiments, hitherto instituted for the purpose of ascertaining the relative degrees of cohesion and conducting power of the different metals, have presented the same results. It is however certain, that copper, gold, silver, platinum, iron and zinc, are the best con-

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* It may be objected, that some bodies which are non-conductors of electricity when solid, become conductors in the liquid state. But it is doubted by Dr. Faraday whether such bodies ever do conduct electricity without undergoing decomposition, as he found that, whenever they act chemically on the plates of a battery, electricity is disengaged. Query. Is it not more probable that the non-conducting power of such bodies in the solid state is owing to the crystalline arrangement of their particles, as in the form of ice or snow? (See *page* 179.)

ductors of electricity,—and it has been shown by M. Becquerel, that potassium is of all others the worst conductor. (*Ann. de Chim. et de Phys.* xxxii. 420.)

In opposition to the simple and rational theory of Franklin, Canton, Wilson and Beccaria, that electricity repels its own particles, and is attracted with various degrees of force by different species of ponderable matter, it has been maintained by Coulomb, Poisson and other philosophers, that *there is no affinity between electricity and ponderable matter*,—and that *it is confined to the surface of bodies by the pressure of the atmosphere.*

Nothing could more clearly illustrate the tendency of mankind to take things upon trust, and without examination, than the general adoption of this partial and erroneous doctrine by numerous modern writers on physical science. It seems to have been founded chiefly on the fact, that electricity escapes from the surface of bodies more readily *in vacuo* than under the pressure of the atmosphere. But it has been demonstrated by Morgan, Cavallo, Ampère and Sir Humphrey Davy, that electrical attractions and repulsions take place *in vacuo* as well as under the pressure of the atmosphere. (See *Philosophical Transactions* for 1822, where the experiments of Davy are recorded.)

It is very true that electricity, in the diffused state, moves more freely over the surface of bodies than through their substance; and that atmospheric air, when perfectly dry, assists in preventing its escape from other bodies, because it is a bad conductor. It was before stated, that an electric spark expands in an exhausted receiver into a diffused lambent light; and

Mr. Harris of Plymouth, has proved that the striking distance of the spark varies inversely as the density of the air through which it passes, the charge being the same. But these experiments afford no proof that electricity is not attracted by ponderable matter. The important practical application of metallic conductors, as lightning rods by Franklin, was founded wholly on their attraction for the electric fluid. It never entered into the imagination of that eminent philosopher, that flashes of lightning are determined to the earth and its conductors by the pressure of the atmosphere.

That electricity, when concentrated, is capable of passing through the substance of bodies, was proved seventy years ago by M. Jallabert of Geneva, who found that it might be readily transmitted through metals, covered over with pitch. (*Priestley's Hist. of Electricity*, p. 127.) But the same thing is fully demonstrated by the fusion of metals, rocks, gems and all other bodies by lightning and other forms of electricity, and by the transmission of shocks through living bodies.

Notwithstanding the mathematical demonstrations of the Coulombian theory, it is founded on hypothetical and false assumptions; and, when applied to the explanation of natural phenomena, is evidently of no practical value. It is therefore not surprising, that Sir John Leslie should have observed, in his History of Physical Science, that it deserved the Dunciad.

To trace the analogies of caloric and electricity through all their diversified manifestations would be an endless task. They are both disengaged from all bodies by friction, pressure, percussion and by chemical

action; but vary according to the manner in which the operation is performed. It was proved by Becquerel, that the intensity of electricity evolved by pressure was in proportion to the force employed; from which it would seem, that, when the particles of bodies are forced nearer together suddenly, a portion of their latent caloric is disengaged in the concentrated form.

The greatest of all mysteries connected with electricity is the protean power by which it assumes an endless variety of forms, under different circumstances. We have seen that voltaic electricity, evolved from a single pair, or from a few series of large plates, with an interposing liquid, differs greatly from that which is obtained from a battery composed of the same materials, but consisting of a great number of smaller plates; and the latter is equally different from the electricity of the atmosphere, or that procured from a common machine. In fine, these differences are as numerous as the circumstances are various under which the phenomena take place. What then? Shall we assume the existence of an indefinite variety of electric fluids? Nothing could be more in opposition to the fundamental laws by which they are governed.

It has been supposed that electricity is far more subtile and refined than caloric, because of the ease and rapidity of its passage through metals and other conductors. This is a partial view of the subject; for caloric passes freely through mica, glass and some other transparent bodies, which arrest the electric fluid when in the concentrated form. Nor is it true that glass is altogether impervious to the electric fluid. Compared with lac, it may be regarded as a conductor;

for electricity produces attractions and repulsions through glass. If a small pith ball be suspended within a glass jar by a fine silk thread, it will be attracted by an electrified glass tube on the outside. It is further stated by Dr. Priestley, that electricity escapes through some species of glass, like water through a sieve. (*History of Electricity*, p. 592.) Besides, if a metallic wire be inserted into a glass receiver exhausted of air, and connected with an electrical machine in action, a stream of electric light is seen to proceed from the wire in a straight line to the plate of the air-pump; but if a conductor be presented to the side of the glass, the electric light is drawn toward it, which shows that electricity is attracted through glass. The same thing is true, to a certain extent, of sealing-wax, as shown by Dufay a hundred years ago; it is therefore evident, that all bodies are permeable to this subtile ether.

The rapid passage of electricity through conductors, and its power of communicating a shock, are the most remarkable properties which distinguish it from caloric. But this difference vanishes when we perceive that it is only electricity of a peculiar tension or concentration that exhibits these powers, and that many of its forms produce no such effects. That the passage of electricity through living bodies, without producing the sensation of heat, is chiefly owing to its velocity, would appear from the fact, that a spark from a Leyden battery may be passed through gunpowder without igniting it, unless retarded in its progress by an imperfect conductor, such as water, when it inflames gunpowder. When electricity of high ten-

sion passes without interruption through conductors, it does not heat them; whereas, if they be too small to allow its free passage, or if the conductors be imperfect, they are heated, fused and volatilized. The same is true of solar caloric, when concentrated by a large burning-glass; for it passes through water and other transparent substances without heating them; but if made to act on bodies that obstruct its passage through them, they are fused, ignited and dispersed in the form of flame.

It has been a leading object of this inquiry to show how partial and erroneous is the prevailing notion, that the agency of caloric is limited to the production of temperature, liquefaction, combustion, &c. It is in its power of producing *motion*, and of maintaining the harmonious action of all the elements, that we are to seek for the laws which connect it with the science of universal nature.

We have seen its mechanical agency in steam; which has given to man a power over matter superior to all the achievements of ancient or modern times, —in gunpowder and other fulminating compounds,— in volcanic eruptions,—and in that process of evaporation by which the rains of heaven are distilled from the ocean, transported through the atmosphere, and deposited in fertilizing showers,—that it holds together the atoms of solids with inconceivable force, and disaggregates them with equal force,—in short, that it is the executive principle in creation.

The mechanical agency of electricity is equally striking, though less constantly exerted. It overcomes the cohesion of all bodies, whether simple or

compound, and acts equally on particles or masses. It transports the different elements of bodies to opposite poles of the battery. Acids may be conveyed through alkalies, and alkalies through acids, to their respective poles without neutralizing each other. It has been shown by M. Fusinieri, that electric sparks issuing from the brass conductors of ordinary machines contain incandescent particles of zinc and copper. When drawn from silver, they contain impalpable particles of silver, that may be seen with a good microscope, and discovered by chemical tests. When a spark issuing from a knob of gold passes through a plate of silver, a circular spot or stratum of gold is seen on the surface of the plate where the spark entered and emerged, which soon volatilizes and disappears; and when it issues from a ball of copper, similar phenomena occur. The spark also acquires new particles from the metal through which it passes. In all such cases, the colour of the spark depends on the nature of the metal thus ignited—from which Fusinieri concludes, that electric light is always combined with ponderable matter; and that lightning owes its luminosity and odour to the combustion of such matter. (*Giornale del Pavia*, 1825.)

Dr. Priestley relates, that when the steeple of St. Bride's Church in London was torn by a flash of lightning, it acted as an elastic fluid; and that its effects were exactly similar to what would have been produced by gunpowder pent up in the same places and exploded.

It is also related by Mr. Lyell, on the authority of

Dr. Hibbert, that at Funzie, in Fetlar, one of the Shetlands, about the middle of the last century, a rock of mica schist, one hundred and five feet long, ten feet broad, and in some places four feet thick, was torn in an instant, by a flash of lightning, from its bed, and broken into three large and several smaller fragments. One of these, twenty-six feet long, ten feet broad and four feet thick, was simply turned over. The second, which was twenty-eight feet long, seventeen broad and five in thickness, was hurled across a high point, to the distance of fifty yards. Another broken mass, about forty feet long, was thrown still farther in the same direction, quite into the sea, while many smaller fragments were scattered up and down. (*Principles of Geology*, vol. i. p. 260.)

A similar effect of lightning was related, not long since, in the German papers. It was stated that an enormous rock had been removed from the bed of a stream in Prussia, by boring a deep hole in it, into which was inserted a bar of iron twenty-eight feet long. The consequence was, that soon after, during a thunder-storm, the lightning was directed to the bar, and the rock shattered to fragments. It would be useless to dwell on the mechanical effects of electricity in rending rocks, trees, buildings, &c., were it not that there are still many writers on natural philosophy, who affect to doubt its materiality; and some who resolve it into undulations of the unknown ether, —as if it could not be bottled up in a Leyden battery like water or any other material fluid,—or as if it did not act upon the sense of sight, hearing, feeling, smell-

ing and even of taste, like other material agents; and as if undulations were capable of causing horizontal, vertical and rotary motion.

It was shown in book ii. chap. ii. *that, other things being equal, the chemical effects of caloric are uniformly in proportion to its absolute quantity.*

It has also been shown by Davy, Children and many other modern experimenters, that both the *heating* and chemical powers of voltaic electricity are in direct proportion to its quantity; and that the quantity evolved is in proportion to the amount of chemical action; corresponding with the universally acknowledged fact that the heat of combustion is in the same ratio.

Without deciding whether electricity be a material agent, *sui generis*, or mere motion of ordinary matter, Dr. Faraday maintains, that "the atoms of matter are in some way endowed or associated with electrical powers, to which they owe their most striking qualities, and among others, their mutual chemical affinity," —and he has endeavoured to ascertain experimentally, the absolute amount of this *agent*, *motion* or *power*, which is associated with the particles or atoms of matter. He found that "*one grain* of water required an electric current to be continued for three minutes and forty-five seconds to effect its decomposition; which current was powerful enough to retain a platinum wire $\frac{1}{104}$ of an inch in thickness, red hot in the air, during the whole time." He therefore concluded, that an equal quantity of electricity is employed in holding the particles of one grain of water together; and that it is probably equal to a very powerful flash

of lightning. (*Experimental Researches in Electricity, sixth series, Phil. Transactions,* 1834.)

He adds, in another section, (873,) that "the chemical action of a grain of water upon four grains of zinc, can evolve electricity equal in quantity to that of a powerful thunder-storm."

If this inference were well founded, the chemical action of a pound of water upon four pounds of zinc, would afford as much electricity as many thousand thunder-storms,—each of which is often attended with from twenty to fifty or more flashes of lightning; so that if the doctor should devise a mode of disengaging it in the concentrated form and in rapid succession, his experiments would eclipse the thunders of Jove.

But this is not the climax of modern discoveries: for if we are to credit the account of Professor Ritchie, "Dr. Faraday has found from a recent experiment that, by the action of electricity on a copper wire, as much light was given out in the course of a few days, as could be emitted from the sun in a year." (*Records of Science,* vol. i. p. 315.) And that this miraculous story was not intended as a satire, would appear from the gravity with which Dr. Ritchie adduces it "as a strong argument in favour of the undulatory theory of light,"—of which he was known to be a strenuous advocate. Nor is it easy to comprehend the philosophy of Dr. Faraday when he says, that "gravitation is a certain property of matter, dependent on a certain force, and it is this force which constitutes the matter." (*Phil. Mag.* 1844.) At the time this new definition of gravitation and matter appeared, a medi-

cal gentleman of London was asked his opinion of its meaning, to which he frankly replied that he "did not profess to understand it," adding, however, that "Dr. Faraday doubtless understood himself." But I must return to my subject.

Like caloric, we have found that electricity fuses the most hard and refractory bodies. As an example of this, we are informed by Becquerel, on the authority of Dr. Fiedler, that in eastern Prussia and Silesia, large glass tubes are frequently found in banks of sand, from twenty to forty feet in length, formed by the sudden fusion of silicious matter by flashes of lightning; and, as might naturally be supposed, that the inner surface of these fulminary tubes is smooth, while the outside is rough. In regard to the mechanical effects of lightning in rending trees, displacing large rocks and perforating the walls of buildings, the community is generally more or less informed.

Again, *like caloric, electricity expands all bodies into flame or light.* But Sir I. Newton, and after him Sir H. Davy, defined flame as gaseous matter raised to a red or white heat: from which it would seem that they both regarded flame as a solution of ponderable matter. And I have already shown that all bodies may be converted into light, whether by heat or electricity; and that its colour varies according to the nature of the ponderable matter employed;* that

* Much additional information might be obtained on this important subject, by submitting all the elements of ponderable matter to the agency of voltaic electricity, separately in succession; and by analyzing their light with a prism, or by causing it to pass through differently coloured transparent media.

potassium, strontium, lithium, boron and some other bodies, burn with a red light; chloride of sodium, with an orange light; oil, tallow and resins, with a yellow light; hydrogen and some others, blue light; and iodine, violet light,—but that when different elements are burned together, the result is a compound light, which may be decomposed by a prism into different primitive colours like the solar rays—in short, that there is no essential difference between electric light and that of ordinary combustion,—and that electricity is never luminous or visible, except when in a state of combination with ponderable matter, as maintained by Fusinieri.

Since the discovery of Œrsted, that a metallic wire which connects the extremities of a voltaic battery in action, is capable of deflecting a magnetic needle placed near it from its ordinary position; and of Davy and Arago, that it is capable of attracting iron filings during the passage of an electric current through it, philosophers have seemed to suppose that the production of magnetic effects was a peculiar and distinctive attribute of electricity. But if it were established, that electricity is a distinct fluid, *sui generis*, it is nevertheless demonstrable, that caloric is capable of producing magnetic phenomena in a still more remarkable and universal manner—and that electricity of high tension, which produces a shock, and darts through metals with the greatest velocity, produces very feeble and partial effects on the magnetic needle, during its passage through a multiplying wire. It was first remarked by Davy, that the magnetic influence of a voltaic current was in proportion to the

heat developed in the wire connecting the extremities of the battery. (*Philosophical Transactions*, 1821.) And it is now universally known, that batteries composed of a few large plates of zinc and copper, or even of a single pair of plates, are the best adapted for exhibiting magnetic phenomena—in fine, that the magnetic power of voltaic electricity is proportional to the quantity evolved, and inversely as its tension or power of communicating a shock—that thermo-electricity which affords none of the usual signs of common electricity, such as diverging the gold leaves of an electrometer and passing rapidly through conductors, deflects a delicate magnetic needle. It was long since observed by M. Œrsted, that common electricity passed too rapidly through metallic wires to affect the needle—an hypothesis which has been confirmed by M. Colladon of Geneva, who found that when the wire was covered with three folds of silk, (which must have retarded the velocity of the electric current through it,) the needle was deflected as by a current of voltaic electricity.

The most important application of Œrsted's discovery was the invention of what has been termed an *electric multiplier* or *galvanometer*, by M. Schweigger of Halle, which has been variously modified by other philosophers. Before the invention of this beautiful instrument, a prepared frog was considered the most delicate test of galvanic electricity. But it has been found, that the multiplier is not only a far nicer test of electricity, but that it is also the most delicate thermoscope ever invented—that one five-hundredth part of a degree of Fahrenheit's thermometer produces

a sensible movement of a small needle suspended by a fibre of silk. From which it follows, that magnetic phenomena are not confined to the action of electricity, but also result from the agency of caloric in quantities too small for measurement by any other test.

It is, therefore, not a little surprising, that when Dr. Faraday offered as a proof, that all the varieties of electricity are essentially the same, because they all produce magnetic effects, that he did not recognize the identity of caloric and electricity.

Guided by the general fact discovered by Œrsted, that a magnetic needle placed over the wire connecting the poles of a battery in action has a tendency to arrange itself at right angles to the conducting wire, Schweigger covered a common brass wire with silk thread, for the purpose of insulating it. This wire was then wrapped round a piece of wood, 50, 100 or 200 times. When its two extremities were connected with the poles of a battery in action, the galvanic current passed through all the windings of the wire, by which the magnetic effects were multiplied with every turn of the wire; so that when a magnetic needle was suspended in the middle of the hank of wire, it was placed at right angles to it. In this way the power of the multiplier was made to detect, not only minute portions of electricity that could not be otherwise appreciated, but the smallest changes of temperature, as before observed.*

* It was also by wrapping a piece of soft iron, bent in the form of a horseshoe, with insulated copper wire, and connecting its extremities with the poles of a galvanic battery, that Professor Moll, of Utrecht, was enabled to convert it into a temporary magnet of great power.

By an improvement of this important instrument, MM. Nobili and Melloni were enabled to detect the heat of phosphorescent wood, dead fish, living insects, and that of the different coloured rays of the solar spectrum. But it was previously discovered by Dr. Seebeck, of Berlin, that when a circuit is formed by soldering together two metals, and applying the heat of a lamp to one of the junctions, a needle placed within it was deflected from the magnetic meridian, and placed at right angles to the metals forming the circuit. It was afterwards found by Dobereiner, that the heat of the hand was sufficient to cause a deflection of the needle, when applied to the junction of the two metals—and by others, that the same effect was produced by applying ice, ether, or anything which alters the temperature in one part of the circuit from that of the rest. M. Becquerel found, that when one end of the multiplying wire was heated and brought in contact with the other end, the needle was deflected. Hundreds of similar experiments might be adduced, all of which demonstrate the agency of caloric in producing magnetism, where there is no sign whatever of electric tension; and that the magnetic needle is a true test of the smallest quantities of caloric that have ever been measured.

Some of the most delicate experiments on record were performed by Dr. Locke, of Cincinnati. By interposing one-quarter of a grain of antimony between the two copper wires of a multiplier, and applying the warmth of his finger, the needle was deflected 22°. In another experiment, one of the copper wires was laid

upon the other, without the interposition of any other metal, and the warmth of the hand applied as before, when the needle was deflected 6°. The same results were obtained by substituting the warmth of the breath instead of that of the hand. The temperature of the room in which the experiments were made was 65° F. (*American Journal of Science*, April, 1834.)

But the most decisive proof that caloric and electricity are only modifications of one and the same agent is, that they are mutually convertible into each other; and that the electric fluid obtained from a permanent natural magnet, fuses, volatilizes and ignites charcoal, metals and other solids, like ordinary caloric.

From a general review of the foregoing chapters, the following conclusions have been deduced:—

1. That the latent caloric of aqueous vapour is the true and only basis of lightning.

2. That the latent caloric of liquids is the basis of voltaic electricity in all its various forms.

3. That they are both governed by the same universal law of attraction for ponderable matter, and repulsion of their own particles.

4. That the essential properties of positive and negative electricity are the same under all circumstances.

5. That when metals are made red hot by electricity, whether it be disengaged from a galvanic battery, a common machine, or from a magnet, it immediately loses its peculiar power of darting through conductors and producing a shock, being transformed into caloric, when it excites the sensation of heat, and

converts solids into liquids, vapours and gases, which present the same properties as if generated by the action of ordinary caloric.

6. That if caloric and electricity be not modifications of one agent, and the cause of all mechanical and chemical action, the whole of modern science is a mere chaos of contradictions.

BOOK IV.

CHAPTER I.

LIFE.

"First, then, if any one think that the secrets of nature remain shut up, as it were, with the seal of God, and by some divine mandate interdicted to human wisdom, we shall address ourselves to remove this weak and jealous notion; and, relying on simple truth, shall bring the inquiry to this issue, not only to silence the howl of superstition, but to draw religion herself to our side."—BACON.

"In physiology, what a vast advance would that philosopher make, who should establish a precise, tenable and consistent conception of life!"—WHEWELL.

THE animating principle, whether considered in a theoretical or practical point of view, is the most important problem that ever engaged the attention of mankind; for it connects all that is profound and fascinating in physics, with the science of preserving health and prolonging life. Never can the healing art take its appropriate rank among the exact sciences, until the cause of vital force and animal motion is distinguished from the operations which it produces; but must remain, as in all the ages that are past, a mere collection of empirical rules. If it be true that every deviation from health is immediately connected with

some derangement of the vital principle, there cannot be a doubt, that a clear comprehension of what it is, and of the laws by which it operates, would do more to meliorate the condition of mankind, than all the systems that have been invented from the age of Hippocrates to the present time; because it would lead not only to a certain method of curing diseases, but, what would be of vastly greater consequence, the theory of life would become intelligible to all; and its chief glory would be the prevention rather than the cure of maladies.

The whole object of medical science is to regulate the forces of life—to increase them when and where they are deficient—to restrain them when excessive—and to restore their natural balance when deranged. But how can we know the best means of maintaining the functions of life in a healthy state, while ignorant of the physical cause on which they all depend? How is it possible to counteract with certainty those involuntary movements that constitute tetanus, hydrophobia, and other forms of convulsive disease, without knowing the cause of muscular contraction in a state of health? How can we adopt the best treatment of fever, inflammation, and the various species of malarious affections, without comprehending the true theory of animal heat, and the specific office which it performs in the economy of life? Why are so many diseases pronounced incurable, though attended with no organic lesion, and ranked among the *opprobria medicorum*, but that men are ignorant of what causes the heart to beat, the stomach to digest, the brain to think, the nerves to feel, and our active limbs to move?

The true panacea, or elixir of life, must not be sought in specifics and nostrums, but in a clear and definite knowledge of the mode in which the organizing principle operates in the different functions of life. Were it not that all the phenomena of nature are linked together as parts of one great whole, it would be of far higher importance to know the cause of vital motion than that of the heavenly bodies. Nor was it ever intended by Infinite Wisdom and Goodness, that knowledge, so essential to the happiness of our race, should remain a sealed book. Life is the problem of problems, the solution of which would clear up a thousand other mysteries, and banish innumerable errors from the pages of science. And it may be asserted with confidence, that whoever is without faith in the power of well-directed efforts to resolve it, will never accomplish much toward enlarging the empire of man over the numerous evils by which he is surrounded. A complete knowledge of this subject would do more to elevate the condition of mankind than the power of transmuting the baser metals into gold, or even charcoal into the precious diamond; for all the riches of the earth are not to be compared with health.

But, unfortunately for the best interests of the world, an impression has long prevailed, that the animating principle is something beyond the powers of the human mind to comprehend. That such dogmas should have been inculcated by the founders of narrow creeds, and individuals interested in keeping the people in ignorance, is not to be wondered at; for in all ages of the world, the empire of imposture has been founded on

pretended msyteries, and upheld by ignorance. It is, however, melancholy to reflect, that philosophers have given countenance to this prejudice. Enslaved by ancient errors, even the wise Socrates is said to have thought it dangerous, unprofitable, and not acceptable to the gods, for men to pry into the hidden mechanism of nature. (XENOPHON, *Cyropedia*, iv. 7.) And in an article on Life, contained in his *Philosophical Dictionary*, Voltaire, a professed champion of free inquiry, asserts, that "the cause of animal motion, like that which determines all things to a common centre, and the needle to the pole, is the secret of the Deity." The general adoption of this opinion by the instructors of mankind has done immense injury to the cause of science, by discouraging the efforts of genius to press forward into the undiscovered regions of truth; while it has fostered ignorance, indolence, and every description of quackery. If there be any primary and efficient cause of vital force, it must be either a portion of the air we breathe, or of the materials by which we are nourished; and if so, there is no good reason why it should be more mysterious than any of the other phenomena of nature.

It was remarked by Cicero, that "to be ignorant of what has been done before our time, is ever to remain in a state of childhood;" and Lord Bacon observes, that "whoever undertakes to investigate the first principles of science, should know the opinions of the ancients concerning the foundations of nature." Coinciding with these views, and having often felt the want of such information, I shall give a brief outline of the leading doctrines which have come down to us from a

remote antiquity, in regard to the primary cause of motion and life throughout nature.

From the earliest dawn of civilization, men sought to resolve this great problem; and there is nothing more remarkable in the history of mankind, than the universal consent with which they regarded elementary fire as the organizing principle; a doctrine which, although but vaguely understood by the ancients, was the basis of all their physiological theories; and which, when clearly unfolded, is destined to survive all the more elaborate systems of later ages, because it was the result of observation, experience and the dictates of common sense.

It was from beholding everywhere the transforming and life-giving power of the sun, as displayed in the generation and growth of organized bodies, that all the early nations of the earth were led to regard that glorious luminary as the Supreme Lord of creation, and as the special object of religious adoration. In accordance with the views of Macrobius, it has been fully established by the learned researches of Bryant, Dupuis, Sir William Jones and many other distinguished oriental scholars, that all the deities of the ancient world are resolvable into the powers of nature, and that they were mythological personations of the sun or solar fire, by which everything is produced.*

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* The primitive solar worship is strikingly illustrated in the following passage, (translated from one of the Vedas, or ancient Hindoo scriptures, by Sir W. Jones,) which also contains the germ of what is called the oriental theory of emanations, referred to in a note to *page* 112, book i.:—"Let us adore the supremacy of that divine sun, the godhead who illuminates all, from whom all pro-

It was because the old Sabeans regarded fire as the universal spirit or soul of nature, that they worshipped the sun, moon and planets, with all the host of heaven, which they represented as the body of God. It was the sun that was adored as the fountain of light, life, wisdom and goodness, in ancient India, under the titles of *Boodh-ha* and *Chreeshna;* which, in the old Celtic language of Ireland, also signify the sun, according to Higgins. (*Anacalypsis*, vol. i. p. 159.) The Baal and Belus of the early Chaldeans were names of the solar orb, which they represented as the seven-rayed god that fills the planets with life, power and harmonic motion. Nor is it less certain, that under the various titles of Saturn, Jove, Osiris, Vulcan, Hercules, Molech, Elion, Adonis, Jupiter, Apollo, Pan, Dionusus, Esculapius and a multitude of other appellations, the worship of fire was practised for thousands of years in Egypt, Phœnicia, Arabia, Persia, Greece, Italy and among all the ancient tribes of Europe.* Nor is it

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ceed, to whom all must return, whom we invoke to direct our understandings aright, in our progress toward his holy seat." (*Asiatic Researches*, vol. i.; *Works*, vol. vi. p. 417.)

It may also be worthy of notice, that in the ancient Sanskrit the seven days of the week are called after the heavenly bodies; Sunday after the sun, to which that day was consecrated; Monday after the moon, Tuesday after Mars, Wednesday after Mercury, Thursday after Jupiter, Friday after Venus, and Saturday after Saturn, as in several of the more modern languages, including French and Italian.

* Under the mythological titles of *Boodh* and *Fo*, the sun has been worshipped from the earliest ages to the present time, in the vast empire of China, where elementary fire is still regarded as the formative principle, which was called *Tien* by the great Confucius and his disciples. Nor is it unworthy of notice, that the ancient

surprising, that in the absence of revelation, all the religious and philosophical systems of mankind should have been founded on the sensible operations of the material universe.

The truth is, that all the names of the Supreme Being in the ancient Hebrew, as in every other written language, seem to have been originally derived from the operations of the sun, light or fire, as we learn from the researches of Bryant, Parkhurst and other learned etymologists.

Innumerable passages might be quoted from both the Old and New Testaments, in which the Creator of all things is represented by the brightness of the sun, and under the similitude of light or fire, as in the burning bush, the lightnings of Sinai, the pillar of fire, the vision of Ezekiel, who beheld brightness and flashes of lightning; that of Daniel, to whom the throne of God appeared like a fiery flame; the representation of angels as fiery spirits or seraphs; and the cloven tongues of fire that appeared on the day of Pentecost.

Persians represented light as the source of all good, and darkness as the evil principle, which, according to Bishop Theodorus, they termed Satana, or Arimanius. (*Enfield's Hist. of Philosophy*, vol. i. p. 64.) We also learn from Macrobius, that in Egypt, as in several other oriental countries, the sun was worshipped under the symbol of a bull, which, like the ram, the serpent and many other animals dedicated to the sun, were regarded as sacred by the vulgar. And so deeply rooted was this superstition among the Israelites, that they made them a golden calf in the wilderness. We further read in the books of the Kings, Chronicles and Prophets, that under the titles of *Baal*, *Moloch* and *Chemosh*, the Chaldean and Phœnician worship of the sun was almost constantly practised by the Jews in groves and high places.

There are also many other passages in the sacred writings in which the Deity is more especially described as residing in, and operating through the agency of light or fire: "who dwelleth in light inaccessible and full of glory—who is clothed with light as with a garment—who maketh his ministers a flaming fire," &c.

Whatever may be the true interpretation of such language, it clearly shows how exalted were the views of the inspired writers in regard to the agency of light in the work of the universe. The plain matter of fact is, that there is nothing in nature so divinely pure, spiritual and beautiful as light. By means of this ethereal medium, we hold communion with the starry worlds, and journey as on the wings of imagination, through the celestial plains. The health and spirits of all animated beings are awakened to renewed energy by the solar rays, but languish in their absence, or when intercepted by mists and clouds. When surrounded with cold and darkness, the brightness of fancy, like the external colours of creation, is quenched, and all the energies of life are brought low.

The unsophisticated language of mankind, in every age and country, has been obviously founded on the intuitive belief, that fire is in some way immediately connected with all the operations of life, sensation and thought. The following expressions are not merely metaphorical, but vivid and faithful representations of nature, derived from experience and observation:—*The lamp of life, the glow of health, the warm vigour of youth, the lustre of a beaming eye, the brightness of fancy, the light of reason, the fire of genius, the heat of passion, the chillness of age, and the coldness of death,*—with a

thousand others that might be adduced, which are not less philosophically correct than poetically beautiful.

In the mythology of Greece, the germs of which were derived chiefly from the traditions of a remote antiquity, the solar orb was represented, under the name of Apollo, as the god of health, poetry and song; or as the *grand dispenser of life, and the universal poet of nature.* The harp of Memnon, that responded in sweet and melodious tones to the rising sun, was probably intended to represent his benign agency in filling the world with music and gladness. When he sheds his beams upon the earth the still air begins to move and resound through the groves with gentle murmurs; while the waves of the sea re-echo with a bolder song. When the sun returns from beyond the equinoctial line, to recall the sleeping world to a new existence, the icy bands of winter give way, when the floods leap forth and join the universal chorus of the living world. The buds of leaves and flowers expand; the fields are clothed with a verdant carpet; the trees with luxuriant foliage; and we can almost hear the fluids gushing through their veins.

The earliest teacher of art among the Greeks was Prometheus, an Egyptian, who has been represented in fable as stealing fire from heaven. But it is probable that he merely taught them the use of fire, in the manufacture of metals, and the other arts of life. Cecrops, who introduced the science of agriculture into Greece, was also a native of Egypt; and Cadmus, who taught the use of letters, was from Sidon. But the most renowned of all the ancient pioneers of civilization among the Greeks, was Orpheus, of Thrace, who,

after visiting the East, is said to have instructed them in music, poetry, religion and philosophy. The sum of his doctrine concerning the origin of things, as collected from the fragments of hymns preserved in the writings of Eusebius, Clemens Alexandrinus, Proclus, Cedranus and Apuleius, and collected by M. Eschenbach, is, that the primitive seeds from which everything was produced, existed from all eternity in a fluid and chaotic state; but that at a certain finite period, the formless mass was reduced to order by the agency of an intelligent, eternal and self-active ether.* (*Enfield*, vol. i. pp. 126 and 130.)

In the *Theogony* of Hesiod, Chaos and Night were represented under the emblem of an egg, over which the Ether brooded, and disclosed the innumerable forms of things. And it is probable that the fable of Cupid and Psyche was an allegorical impersonation of passive matter, and of the principle by which it is actuated; or that Cupid was intended to represent the

* The views of Orpheus concerning the nature of this ether, and its omnipresent agency in the phenomena of life, may be further seen in the fragment of a hymn, *De Mundo*, translated by M. Good:—

"Jove is the ether, Jove the boundless fire,
That fills the world with feeling and desire."

As also in the following beautiful invocation to light:—

"O thou who fillest the palaces of Jove,
Who flowest round sun, and moon, and stars above;
Pervading, bright, life-giving element;
Supernal ETHER, fair and excellent,
Fountain of hope and joy, of light and day,
We own at length thy tranquil sway."

universal attraction that causes the loves of the elements, and binds the universe together.

The generation of the world from a fluid and chaotic state, was a leading doctrine in all the ancient oriental cosmogonies, from the time of Moses, Orpheus and Hesiod, down to the period of Ovid; and may be traced in the writings of Aristotle, Epicurus, Zeno, and the Stoics generally. For example, we are informed in the first chapter of Genesis, that "in the beginning, the earth was without form, and void, and darkness was on the face of the deep." And it is related by Berosus, that the ancient Chaldeans maintained, that in the beginning, all things consisted of a dark fluid mixture, that was separated and reduced to order by the divine power of Belus, (light;) and that the human soul is an emanation from the divine nature. (*Enfield*, vol. i. p. 54.)

The Egyptian magi also maintained, that before the regular forms of nature arose, an eternal chaos existed; but that the passive and formless mass was reduced to order by the agency of a self-active, intellectual and eternal ether, which gradually developed all that we behold of the external universe. (*Idem*, pp. 89 and 132.) The sum of the Phœnician cosmogony, as related by Cumberland, on the authority of Sanchoniathon, is, that the elements of all things originally existed in a fluid and chaotic state, until called forth by the energy of a self-active principle, in obedience to the laws of an immutable necessity. It is therefore evident that the generation of all things from chaos was a fundamental tenet in most of the ancient theogonies, as described by Ovid:—

"Ante mare. et terras, et quod tegit omnia cœlum,
Unus erat toto naturæ vultus in orbe
Quem dixere chaos, rudis indigestaque moles,
Nec quicquam nisi pondus iners congestaque eodem
Non bene junctarum, discordia semina rerum."
(*Met. Lib.* I. v. 5.)

Whatever may have been the origin of this widely diffused tradition, it contains at least a nucleus of truth; for it is certain, that all the forms of nature with which we are acquainted, have actually emerged from a fluid state. The primitive mountains of the globe have been formed from a state of fusion by fire —and the sedimentary rocks from a state of solution in the water of lakes and seas; or from the ruins of mountains and elevated plains, that have been carried down by rains, rivers and springs, in a state of chaotic mixture. Plants are formed from sap, and animals from blood, in which all their organs are confounded, until developed by the powers of life. And if it be true that the planets have been formed from the aggregation of phosphorescent nebulous matter, in which all the elements, active and passive, are mixed up and confounded, it presents the most important physical conditions of the ancient chaos. The successive destruction of the world by alternate submersions and conflagrations, and its renovation from a state of dissolution, was another doctrine of antiquity, that may have originated from a confused notion of the perpetually destroying and regenerating influences that make up the history of universal chemistry, geology, life and death.

The first philosopher who introduced an exact method of studying nature among the Greeks, was Thales of Miletus, who was descended from Phœnician parents, and flourished about six hundred years before the commencement of our era. This illustrious founder of what has been called the Ionian school, after travelling through the East, for the purpose of acquiring knowledge among the renowned magi of Egypt, returned to his native country, where he laid the foundation of mathematical and physical science on the basis of established principles. With the sages of the oriental nations, he maintained the existence of an omnipresent fiery ether, as the primary efficient cause of motion throughout the universe; and which he termed αυτοκινητον, for the purpose of representing its self-moving power. According to Cicero, he also regarded it as the soul or mind of universal nature, because he conceived that a self-moving principle, wherever it exists, must have intelligence. (*De Naturâ Deorum*, lib. i.) Aristotle termed it κινητικον, as indicating its power of giving motion to other bodies. (*De Anima*, lib. i. c. 2.) By the energy of this principle, Thales maintained that the passive elements of matter were reduced to order from a fluid state, and that it is the proximate cause of life in plants and animals.

In conformity with the above doctrine, Parmenides and Archelaus maintained that heat was the cause of motion, and cold of rest; or that heat and cold were the first principles of action in nature. Heraclitus also regarded fire as the cause of energy throughout

the universe; and as it seemed to produce all effects in a regular series, in obedience to perfectly wise laws, he conceived that it must be omniscient and divine.

It has been often asserted by both ancient and modern writers, that Democritus denied the existence of any independent principle as the primary and efficient cause of motion and life in the universe, distinct from the primitive, indivisible and immutable atoms of matter; which he supposed were all of the same essential nature, but different in form and magnitude. It has been said that he referred all the generations and dissolutions of bodies to certain innate forces of attraction and repulsion, residing in these ultimate atoms; and that the various properties of bodies are owing to the different mode of their arrangement, as determined by the inherent powers of atoms. But Lucretius says that Democritus regarded heat as composed of exceedingly small atoms of a round form, more active and penetrating than those of other matter; and the soul, or animating principle in man, as a portion of the same fiery nature that actuates the universe. With very slight variations, the Epicurean theory of physics was a copy of the above doctrines.

Another distinguished teacher of natural philosophy among the Greeks was Pythagoras, the son of a Tyrian merchant, born in the island of Samos, 586 A.C. After visiting the different countries of the East, and residing twenty years in Egypt in quest of wisdom, he established a school of science in his native place, and afterwards at Crotona in western Greece, from which he was driven by persecution to Metapontum, where he is said to have perished of hunger in the Tem-

ple of the Muses, a martyr to the ignorant jealousy of his enemies.

The sum of his doctrine concerning the *primum mobile* of nature was, that it is an all-pervading fiery ether of boundless energy, possessing within itself the united power of motion and intelligence, αὐτοματισμὸς τῶν παντῶν, *the self-moving principle of all things;* and that the human soul is a portion of the same essence. This first principle of action in nature he represented as *unity;* the passive elements of matter as *duad;* and the universe perfectly formed as a physical *triad*, all the operations of which are governed by exact numerical laws. He also maintained that the earth and heavenly bodies revolve around a fixed fiery globe; and that the spheres of the different planets, by striking against the ether through which they pass, must produce sounds that vary according to their magnitude, velocity and distance from the centre of the motion—those which are farthest off producing the deepest, and the nearest the highest tones:*

> "Forever singing as they shine;
> The hand that made them is divine."—ADDISON.

Whether anything more was intended than to represent the harmonious relations between the times, distances, magnitude and velocity of the heavenly bodies, the music of the spheres† is the finest conception of

* Aristotle, *Meteor*, lib. i. c. 6; Plutarch, *de Placila Philosophorum*, lib. iii. c. 2.

† The earliest mention of this celestial harmony is found in the Book of Job, where it is said that when the work of creation was

all antiquity, and is said to have led Kepler to the most important discovery ever made in astronomy; viz., that the times in which the planets perform their revolutions are as the cubes of their distance from the sun. Nor is it unworthy of notice, that as the velocity of the planets is in proportion to the heating power of the sun, so the velocity with which sounds are propagated through gases and other vibrating media, is in proportion to the amount of caloric around their particles, *ceteris paribus*.

About fifty years after Pythagoras, arose Hippo-

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finished, "the morning stars sang together;" and it has been consecrated by the noblest poets of modern times.

> "Look how the floor of heaven
> Is thick inlaid with patines of bright gold:
> There's not the smallest orb 'mong all which thou behold'st,
> But in its motion like an angel sings,
> Still quiring to the young-eyed cherubim," &c.—SHAKSPEARE.

It is also grandly expressed in the following lines from an ode of Milton on the Nativity:—

> "Ring out, ye crystal spheres,
> And let your silver chime
> Move in melodious time,
> And let the base of heaven's deep organ blow;
> And with your ninefold harmony,
> Make up full concert to the angelic symphony."

A still more philosophical account of this great music is contained in the opening chorus of Faustus, by Goëthe, who refers it to the fountain of all harmony:—

> "The sun his ancient hymn of wonder
> Is pouring out to kindred spheres,
> And still pursues with march of thunder
> His preappointed course of years," &c.

crates, who flourished in the age of Anaxagoras, Socrates, Heraclitus and Democritus, when Greece was the centre of light and civilization to the whole world. To this illustrious man is due the glory of having reduced the healing art to a regular and systematic form. He maintained that, although it is not the province of the physician to speak of divine things, unless so far as they may serve to improve our knowledge of the causes and nature of the diseases incident to the human body, it is yet necessary for him to lay down some general principle from which he may reason. He then declares his opinion, that elementary fire is the cause of perpetual motion throughout the universe, and when united with organized bodies, constitutes the animating principle; that it resides in all matter, producing an endless variety of effects, according to fixed and definite laws; and that, as it operates with consummate skill in the generation of animal motion, sensation and intelligence, it must be something immortal, that sees, hears and knows all things. This mighty agent, which he terms φυσις or *nature*, was supposed to produce all the phenomena of living bodies, by attracting what is necessary for their development and expelling whatever is superfluous or injurious; and he maintained that the science of medicine should be founded on a comprehensive knowledge of the mode in which it governs all the operations of nature; κατα φυσιν θεωρεων. (*De Principiis, et de Alimento.*)

He maintained that the solid parts of animals, and their various secretions, were formed from the blood, which was composed of four primary humours, cor-

responding with the four proximate constituents of modern physiologists, viz., red particles, fibrine, albumen and serum.* But he supposed that the liver was the great organ of sanguification, and termed the cardinal humours, red blood, black bile, yellow bile and phlegm. On the qualities and relative proportions of these four humours, all the diversities of the constitution were supposed to depend. An abundance of red blood was marked by a warm and sanguine temperament; whereas, an excess of yellow bile produced the choleric temperament, both of which were warm and characterized by a high degree of vital energy. On the other hand, the melancholy temperament was supposed to arise from an excess of black bile, and the phlegmatic from a predominance of phlegm, both of which were cold and marked by a general debility of the system. But it is evident that what Hippocrates called phlegm was only another name for the serous portion of the blood; and that he confounded the dark venous blood which abounds in feeble, melancholy constitutions, with black bile. It is equally certain, that what he called red blood was what we term arterial blood, the abundance of which is marked by a vigorous, sanguine temperament. And there is good reason to believe, that the yellow bile of Hippocrates was only another name for the coagulating

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* In his treatise on the *Nature of Man*, he observes, that "when a man has been mortally wounded by cutting his throat, blood flows first, which is very hot and very red; after which it comes mixed with phlegm, and finally with much bile." From which it would appear, that he regarded phlegm and bile as constituents of the blood.

lymph or fibrine, as he supposed that it imparted a yellow colour to the watery portion of the blood; for the bile secreted by the liver never produces this effect, unless when the system is in a diseased state.*

* Several passages were published in the *Lancet* of September, 1835, by Mr. Girtin, from the writings of Hippocrates, which, taken separately, would seem to show that he was acquainted with the circulation. For example, in his treatise, *De Insomniis*, as quoted by Mr. Girtin from the Vander Linden edition of his works, he observes, that "rivers return to their sources in an unaccountable and extraordinary manner, like the circulation of the blood." (Tome i. p. 460.) In another treatise, he says, "I protest I know not where it begins nor where it ends, for in a circle there is neither beginning nor ending." (*Idem, De Alimento*, tome i. p. 596.) "The heart and veins are always in motion." (*Idem, De Principiis*, tome i. p. 116.) In the *Timæus*, Plato also represents "the heart as the fountain of both the veins and of the blood, which is vehemently impelled through all the members of the body in a circular progression." And here it is necessary to observe, that by φλεβς, veins, the ancients meant all vessels that convey blood. There is a similar passage in Seneca, who speaks of the blood, the circulation of which maintains the vital caloric: "Unde sanguinem cujus cursu vitalis continetur calor." (*De Beneficiis*, lib. iv. c. 6.) But there are many passages in the writings of Hippocrates, Plato and Aristotle, which prove that they regarded the arteries as destined to convey spirits and heat to all parts of the body, and the veins as blood-vessels. When describing the use of different parts of the body, Galen says, that air was supposed to be taken into the lungs, where the most pure and subtile portion was separated from it, conveyed from the trachea to the heart, and thence to all parts of the body by the arteries, which were called *pneumatic vessels;* and that the fuliginous portion of the air was thrown off from the lungs by expiration. He further states, that all the Greeks, from Hippocrates down to his own time, believed that after food was dissolved in the stomach, it was conveyed to the intestines and thence to the liver, where it was converted into

The pathological views of Hippocrates were founded on the above doctrines. He taught, that whatever alters the natural condition of the fluids, whether impure air, bad diet, want of rest, fatigue, retention of the excretions, or the depressing passions of the mind, deranges the healthy condition of the whole system; that inflammation or fever is an effort of nature, or the φυσις to expel morbific matter from the humours; and that the highest wisdom of the physician is to follow the proceedings of nature in practice: above all, to preserve and restore the healthy condition of the blood by nutritious food, pure air, exercise, &c.; to moderate its motions when excessive, and increase them when languid; to open the bowels, skin and other emunctories when obstructed, and dissipate or resolve tumours by fomentations or cataplasms.

If we pass in review the leading doctrines of the different philosophical sects that arose from the Ionian and Italian schools, we shall find that, while on some points they differed from Thales and Pythagoras, they

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blood, prepared for nutrition, and then conveyed to the *vena cava*, to be distributed to all parts of the system; he further taught, that the office of respiration was to *cool* the blood. (*De Usu Partium*, lib. iv.) It was not until the time of Herophilus and Erasistratus, that the brain and nervous system were fully recognized as the organs of sensation, perception and voluntary motion. Nor was it until the middle of the sixteenth century, that Servetus distinguished the pulmonary circulation from that of the general system, or that the lungs were discovered to be the organs of sanguification. It is therefore clear, that the knowledge of the Greeks in regard to the specific office of the lungs, heart, liver, blood-vessels and nerves, was not only vague and imperfect, but fundamentally erroneous.

nearly all maintained that heat is a self-active principle, and the noblest of the elements. Plato, who was born thirty years after Hippocrates, regarded the soul of the world as an all-pervading fire; and he argues in the *Timæus*, that it is endowed with intelligence, or it could not produce animal motion, sensation and cogitation in organized bodies.

But he maintains elsewhere, that the first Mover is an incorporeal, immutable and eternal intelligence, not appreciable by the senses, the Being of beings, and the Fountain of all law; that the visible forms of nature have been organized by an active principle, possessing the power of moving itself, and of generating organized bodies, after the model of certain ideal archetypes that reside in, or emanate from, the UNCREATED, SUPERESSENTIAL AND ALL-BEAUTEOUS MIND;—by which it is probable, he meant to represent the eternal conceptions of the Infinite Mind in framing the laws of the universe. At one time he refers the origin of evil to the creation of the world by inferior divinities; at another, to an inherent stubbornness, or imperfection of matter, that could not be entirely overcome by the Supreme Architect.*

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* There is reason to believe, that a more profound knowledge of nature than the human mind has ever yet attained, will show that all the works of God are absolutely perfect in their kind; and that

"All partial evil is universal good,
All discord harmony not understood."

In the great circle of unceasing change that makes up the order of things, the earthquake and volcano produce apparent disorder, and sometimes destroy life; but without them the earth would not be fit for the habitation of man. The hurricane and tempest are

In the treatise of Aristotle concerning the soul, or animating principle, he maintains that a self-active spirit, which he terms *Πνευμα* or *Ψυχη*, is the cause of all effects in the living body. To this spirit he ascribed three different faculties; the first of which was manifested in the thorax, and termed vital; the second, or nutritive, in the abdomen; while the third, or reasoning faculty, was supposed to reside in the head. He adds, that whether the vital principle be identical with elementary fire, or something analogous, constituting a *fifth* element, it is a portion of the same

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as necessary to the salubrity of the air, as sunshine and rain to the growth of vegetation. And it is probable, that to a superior intelligence, death would not be regarded as an evil, any more than the ripening and decaying of fruits, or the successions of winter and summer, light and darkness. In short, everything in the fundamental constitution of nature, and mechanism of the living frame "*is very good;*" *and tends to produce the greatest amount of happiness to the greatest number of animated beings.* Even the passions of the human mind are as necessary to happiness as reason itself; nor is it possible that pleasure could exist without sensibility, or the susceptibility of pain. Let us then confess, that by far the most fruitful source of physical and moral evil is our ignorance of the innumerable springs of happiness that a more perfect knowledge of nature would unfold. The truth is, that the choicest blessings of life become evils when misapplied. The cherishing power of heat, without which nothing could exist, becomes a consuming fire in excess; and so of our food and drink, exercise, repose and everything else. The beautiful light of the sun, the physical source of all good, excites inflammation of the eyes, if ignorantly gazed at too long. Nor is it unworthy of notice that misfortune and sorrow have been, far more frequently than prosperity, instruments of good, by leading thoughtful minds to investigate the causes of human suffering, and the best modes of preventing it.

principle that maintains the universe in a state of perpetual motion. (*De Anima*, lib. i. c. 2.)

But in his metaphysics, he maintains that the First Mover is incorporeal, immutable, immovable and independent of the material universe. In what way this immaterial First Mover, itself incapable of motion, communicates motion to other bodies, he never clearly explained; but supposed that it acted on the first celestial sphere in a mode similar to that in which the mind acts on the body. (Lib. xi. c. 6, 7, 8, as cited by Enfield.)

As for the rest, he maintained with Plato, that the earth is the centre of motion to the planetary spheres, the velocities of which are inversely as their distance from the first sphere. (*De Cœlo*, lib. ii. c. 13, 14.)

It was observed by Bacon, that Plato corrupted natural philosophy by mixing it up with theology, as did Aristotle by metaphysical refinements and a sophistical logic. That they were both exceedingly ill informed concerning the nature of heat, will appear from the following examples. Plato says, "it is composed of very fine particles that separate and dissolve bodies, but cold of grosser particles that press upon, and shut up their pores." (*Opticks*, vol. ii. p. 100.) From which it is clear, that he confounded a mere privation, or diminution of heat, as darkness is of light, with a material agent; and that he knew not how the same agent produces the opposite effects of attraction and repulsion. Aristotle regarded heat and cold as the cause of density and lightness; but maintains that fire is composed of heat and dryness; air of heat and moisture; water of cold and moisture; earth

of cold and dryness; thus confounding mere qualities and modes of being with material agents. Epicurus also maintained that cold is composed of irregular particles that hold bodies together; and that the vital principle is composed of heat, united with different gases,—*calor vitalis ventusque.* (LUCRETIUS, *De Naturâ Rerum*, book iii.)

Cicero relates that Zeno, Cleanthes and the Stoics generally, maintained the existence of an all-pervading fire as the animating principle, or soul of nature; but that it was governed by the eternal laws of an immutable necessity, which they termed Fate, or Jupiter; and that the mind of man is a spark of the same ethereal principle; that as the loss of *heat* is always attended with the extinction of life, sensation and thought, it must be a spirit or mind. Cicero adds, "Quoniam ex mundi ardore motus omnis oritur, autem ardor non alieno impulsu sed sua sponte movetur animus sit necesse est." (*De Naturâ Deorum*, lib. ii. c. 12.)

And when summing up the opinions of the most distinguished philosophers of Greece, he observes, that "whatever the nature of the Divinity may be, whether air, fire or the fifth element of Aristotle, the human soul is a portion of the same divine nature; that every one is conscious of having within him a something capable of self-motion; and that a principle possessing such a power must be the fountain of motion to everything else, therefore immortal, according to the reasoning of Socrates and Plato. Hence the swiftness of thought, the powers of memory, the pleasures of heroic virtue; the joy with which we contem-

plate the boundless extent of the starry heavens, the earth and sea; and the delight with which the soul traces its connection with the Eternal Reason from which all causes proceed." (*Tus. Disp.* lib. i. c. 23.)

Similar views were entertained by Seneca, and the most celebrated of the Roman poets, who speak of the *anima mundi* as an all-pervading fiery ether, which they regarded as the cause of motion throughout nature, and of life in men, beasts and birds, as in the following lines from the 6th Æneid of Virgil:

"Principio cœlum, ac terras, camposque liquentes
Lucentemque globum lunæ, Titaniaque astra,
Spiritus intus alit, totamque infusa per artus.
Mens agitat molem, et magno se corpore miscet," &c.*

The fire that was kept perpetually burning in the Temple of Vesta, termed *calor vitalis,* and *ardor cœlestis,* was also a type of that eternal globe of fire, the sun, from which it was kindled.

From the foregoing brief summary, the following conclusions may be deduced:

1. That amidst the innumerable conflicting opinions that have prevailed among the most enlightened nations of antiquity, they nearly all united in the belief

* "Know first, a spirit with an active flame
Pervades and animates this mighty frame;
Runs through the watery worlds, the fields of air,
The ponderous earth, the depths of heaven, and there
Glows in the sun, and moon, and every star:
Thus mingling with the mass, the general soul
Lives in the parts, and animates the whole."—WARTON.

that fire is the active principle in nature, and the physical cause of life.

2. That the whole universe is composed of two descriptions of matter, the one active, the other passive; and that everything has been formed from a fluid or chaotic state.

3. That, with very few individual exceptions, they have all maintained the existence of an Intelligent First Cause; whether united with, and constituting the informing mind of the stupendous whole, as taught by the Chaldeans, Egyptians, Phœnicians, Hindoos, Orpheus, Thales, Pythagoras, Hippocrates and the Stoics; or existing apart from nature, as an incorporeal Intelligence, who governs the universe by delegated laws.

4. That Bishop Berkeley was right in vindicating the ancients from the charge of Atheism, (however erroneous their views concerning the Divine Nature may have been,) which is wholly incompatible with their almost universal belief in a presiding Intelligence.

It was observed by Cicero, that "the higher we ascend toward the origin of antiquity, or the divine descent of knowledge, the more clear are the traces of truth." And notwithstanding many striking exceptions might be adduced in opposition to this remark, it is extremely probable that in the primitive ages of the world, before it was filled with books, and the attention of men withdrawn from the study of things to that of words, they were more open to the genial impulses of nature, and communed with her more familiarly face to face.

In support of Cicero's opinion, it may be worthy of notice, that in the Books of Moses, though not intended to teach the principles of natural science, two fundamental doctrines of physiology are incidentally pointed out. I allude to *the life-sustaining office of the lungs, and the vitality of the blood.* For when it is said, as in the first chapter of Genesis, that "God breathed into the nostrils of man the breath of life, and he became a living soul," we can understand only, that he was created with breathing organs, for the purpose of obtaining life from the atmosphere, which, in the Book of Job, is termed "the breath of the Almighty." And it is said in the Levitical code, that "the life of all flesh is the blood thereof." (*Gen.* ix. 11; *Levit.* xvii. 14; *Deuter.* xii.) "He hath poured out his soul unto death." (*Isa.* liii. 12.) The truth of these doctrines is corroborated by the universal language of all enlightened nations, with whom, *to live*, and *breathe*, are synonymous phrases; and who have always represented the destruction of life by the shedding of blood.*

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* It may here be worthy of notice, that throughout the Old Testament, as in all the writings of the Greeks and Romans, the word soul is used for life. "I shall require back your souls from the hands of both man and beast." (*Leviticus.*) In the following lines from Homer's *Iliad*, translated by Pope, the living principle is represented as escaping with the blood:

> "The vital spirit issued at the wound,
> And left the members quivering on the ground."

And in the description of a dying hero by Virgil, the soul is identified with the blood:

> "Purpuream vomit ille animam."—Æn. ix. l. 349.

Again, the true doctrine of the solar system, which seems to have been partially anticipated by Pythagoras, was rejected by all his successors, down to the time of Copernicus; while the atomic theory of Moschus, Thales, Pythagoras, Anaxagoras and Democritus was rejected by Plato, Aristotle and the Stoics, who maintained that the different elements are mutually convertible into each other. Besides, the universal doctrine of the ancients, that all space is filled with subtile matter, is supposed to have been rejected by Epicurus, who is generally understood to have maintained the vacuum of space.*

But with all due reverence for the wisdom of the ancients, it must be acknowledged, that they never fully established any one great principle in physics, capable of widely-extended application to the benefit of mankind. Many of their views were simple, ingenious and grand; but their knowledge of natural history, including geography, geology, mineralogy, chemistry, botany and comparative anatomy, was far too limited to form the basis of a comprehensive theory. And notwithstanding the high importance attached by

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* Mason Good says, "it required 3000 years to render the doctrine of a vacuum probable, and 5600 years to establish it on a solid foundation. For its probability, we are indebted to Epicurus; for its certainty to Sir Isaac Newton." (*Book of Nature*, vol. i. p. 343.) But the following lines from Lucretius, translated by Good, leave it doubtful whether any of the ancients ever believed in a perfect vacuum :—

> "The myriad seeds of fire dispersed at large
> Through all things, back to the same fountain flow;
> And hence well forth o'er all the exulting world
> In boundless flood."

the Greeks to the agency of fire in the phenomena of nature, they never made anything like a regular and systematic attempt to point out the laws by which it operates, in separating and recombining what they called the elements of air, water and earth. Nor did Hippocrates explain the manner in which animal heat is derived from the atmosphere by respiration; how it is connected with fever, inflammation and the various forms of disease. The same observation applies to all his successors, down to the time of Galen, against whom Bacon brought the heavy accusation, (which applies equally to the modern teachers of medicine,) that "he took away the infamy of ignorance in physicians, by declaring so many diseases incurable; thus paralyzing their exertions, cutting off the hopes of improvement, and proscribing the sick." It was therefore justly observed by this great reformer of science, that "inventions for enlarging the power of man over the university of things must be sought in the light of nature, and not in the dim shades of antiquity."

From the decline of Grecian and Roman civilization, until the revival of learning in the fifteenth century, was a long dreary night of ignorance and superstition. The great book of nature, "writ by God's own hand," which speaks a language more instructive than that of men, was exchanged for the mystic jargon of the schools; and the voice of truth was drowned by the clamour of bigotry. But about this time a new era began to dawn upon the darkened world. By the reformation of Luther, the fountains of thought were renovated throughout Europe. The invention of gunpowder, the art of printing, and the directive power

of the compass, did more to improve the condition of mankind, than all the united discoveries of antiquity. For the first time in the history of our race, the true theory of the solar system was established by Copernicus and Kepler. By means of the telescope an highway of communication was opened up with the heavenly bodies by "the starry Galileo," who demonstrated the annual and diurnal motions of the earth; for which he was denounced as the enemy of religion, and the propagator of false philosophy.*

For the first time in the history of science, the circulation of the blood was systematically established by the immortal Harvey, for which he was rewarded with persecution, accused of "confounding all medical theory, and of rendering physiology unintelligible." Truly may it be said, that prejudice is a frightful ogre, and bigotry a very fiend. Then arose Bacon with a holy zeal, and proclaimed, "Only let men awake and fix their eyes one while on the nature of things; another while on their application to the benefit of mankind." The ghostly ministers of superstition had long denounced the knowledge of nature as dangerous; but Bacon showed it to be "more beautiful than any apparel of words that can be put upon it," and the true foundation of human happiness,—without which even religion is perverted into an engine of oppression and misery.

It is not my object to examine all the metaphysical,

* When summoned before the Inquisition for maintaining the motion of the earth, and required to give his reasons for such a heresy, he was answered by the commissary of the holy office, "Terra autem in eternum stabit, quia terra in eternum stat."

mechanical and chemical theories of life that have arisen and passed away since the time of Harvey. So vast are the troops of error, that to notice them all in detail would be an endless task. It would doubtless be far better to establish one important truth, than to refute a thousand errors; or, as Bacon observes, "to set up one great light, or branching candlestick of lights, than to go about with a watch-candle in every corner." Yet as it is necessary to know what has been done, that future inquirers may know what remains to be accomplished, I shall devote the remainder of this chapter to a brief review of the leading doctrines on which the modern systems of medicine have been founded.

Amidst the revolutions of empire, religion and philosophy, that followed the decline of Grecian and Roman civilization, the establishment of Christianity, and the rapid diffusion of Mahometanism after the sixth century, the doctrines of the ancients in regard to the agency of fire as the ruling principle of nature, seem to have shared the same fate as that of the heathen mythology.* It is true that Harvey represents what he termed *calidum innatum* as the immediate cause of vitality in the blood, and of the heart's action. But so vague were his views of its nature and laws, that he describes it as something different from

* Had knowledge continued to advance from the time of Cicero, Seneca and Galen, until that of Bacon, Galileo and Harvey, as it did from the epoch of Pythagoras, to the time of Galen, the physical and moral condition of mankind would probably have been elevated as far above what it now is, as the civilization of modern Europe has surpassed that of the New Zealanders.

solar heat, or that of combustion; and sometimes called it the *naturâ naturans*, or the *facultas vegetativa.* (*De Generatione*, p. 170.)

The truth is, that nearly all the great writers of this epoch recognized the existence of an active principle in nature, as the cause of motion and organization, to which they gave different names; but without identifying it with any known agent. The *Archeus* of Paracelsus and Van Helmont was only another name for the πῦρ Νοερον of Pythagoras, Heraclitus and Hippocrates; for they maintained that it was diffused throughout all matter, and operated with consummate intelligence in the formation of mineral, vegetable and animal bodies; that vital heat is generated in the blood by fermentation, through the agency of the animal spirits, derived from the air by breathing; that food is dissolved in the stomach by means of an acid liquor, and not by the agency of heat, because digestion is carried on in cold-blooded animals, and arrested in man during fever—in short, that all the functions of life are governed by the immediate agency of an intelligent principle.*

The *pneumatical body* of Bacon was clearly derived from the πνευμα of the early Greek philosophers; for in his *Treatise on Life and Death* he represents it "as the master-workman of all effects in the living body;"

* This doctrine, which seems to have been almost universal among the ancients, has been recently revived by Isaac Taylor, who maintains that, in all cases, *mind alone is capable of putting matter in motion;* that it is the cause not only of muscular contraction, but of secretion, nutrition, &c. (*Physical Theory of another Life.*)

while, in various other parts of his *Natural History*, he describes it as an imponderable spirit, and the *cause of evaporation*, germination, fermentation, putrefaction, &c. It is therefore evident that Bacon regarded it as the efficient cause of mechanical, chemical and vital action. Yet, so far was he from recognizing its identity with the elementary fire of antiquity, that he represents heat as a mere effect, condition or property of other matter. On the whole, his views of the animating principle were less accurate than those of Servetus and Harvey, who maintained that it was derived from the atmosphere by respiration, imparted to the blood in the lungs, giving it a bright florid hue, and as possessing the vigour of heat to produce motion.*

The *vital*, *natural* and *animal spirits* of Descartes and his numerous followers of the seventeenth century, were identical with the πνευματα of Galen, to which he referred the faculties of generating animal motion, sensation and intelligence, according to the different parts of the system in which they resided, as the thorax, abdomen, brain, &c. But so ignorant was Galen in regard to the source of animal heat, that he sometimes speaks of it as an inherent condition or property of living bodies, diffused from the heart through the arteries to all parts of the system, in connection with the *pneumata*, or spirits;† and he sup-

* The same active principle was recognized by Dr. Henry More, as the *spirit of matter*, and by the learned Dr. Ralph Cudworth, as the *plastic* principle of NATURE.

† In regard to what these spirits are, the celebrated Harvey observes: "Opinions are so conflicting that it is not wonderful that they should serve as a common refuge for ignorance; and that when

posed that the principal object of respiration was to cool the blood. The same doctrine was taught by Silvius, Fabricius, Harvey, Bartholine, Swammerdam, Morozzo and Cigna; while Borelli, Boyle and many others belonging to the mechanical school, down to the time of Haller, maintained that animal heat was produced by the motion of the blood, and friction of different parts of the body, because the temperature of animals is increased by motion and exercise.

The *ether* of Sir Isaac Newton, to which, in various parts of his later writings, he referred gravitation, cohesion, capillary attraction, the emission, reflection, refraction and inflection of light, the elastic force of gaseous bodies, and the power of menstrua to dissolve solids, was identical with the Αιθερ of Hippocrates, and the ancient sages of the East. He further suggests, in the *Third Book of Optics*, that "animal motion may be performed by the vibrations of this ether, excited in the brain by the power of the will, and propagated thence through the capillaments of the nerves into the muscles, for contracting and dilating them."

It is therefore evident that Newton did not always regard attraction and repulsion as ultimate phenomena, but that he referred all the operations of nature, including animal motion, to what he termed an "unknown ether," which I have shown to be identical

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men are at a loss to assign the cause of any thing, they very commonly reply that it is done by the spirits." He adds: "As to those who advocate incorporeal spirits, they have no ground of experience to stand upon; their spirits being synonymous with powers or faculties." (*Works*, ed. by Willis, p. 116.)

with caloric. Yet so imperfect were the views of this great mathematician in regard to the nature of heat, that he represents it as an *effect* of motion and vibration. Had he been aware that the velocity of the planets through their orbits is directly in proportion to the heating power of the sun, which varies inversely as the squares of the distance, he would not have referred their lasting motions to a single impulse, exerted through a vacuum. Or had he known that the quantity of life diminishes from the equator to the polar regions, like all the mechanico-chemical transformations of matter, he would not have regarded comets as destined to supply the planets with vitality. But as he confounded the cause of motion, of climate, of changes of season, of the growth of vegetation, &c. with vibrations of an ether which he never identified with any known agent, it is not very surprising that his physical speculations have been little understood.

During the time of Newton, it was discovered by the experiments of Boyle, Hooke, Mayow, Bathurst and Henshaw, that during the process of respiration a portion of atmospheric air underwent the same change as in ordinary combustion; by which its elasticity was greatly diminished, and its property of supporting life destroyed. Mayow supposed that a *nitro aërial spirit* was imparted to the blood in the lungs. But in accordance with the reigning fashion of the day, animal heat was referred to innate powers of the system, or to motion of the blood, its friction against the solids, &c.

From the times of Homer, Hippocrates, Galen and Celsus, down to the period of Harvey and Sydenham,

the animating principle was supposed to be conveyed to all parts of the system with the blood, which was thought to be the immediate source of all diseases. But after the attention of physiologists was awakened to the importance of the brain and nerves, by the researches of Willis, Malpighi and others, it was maintained by Stahl, Hoffman and Mead, that all the functions of animal life, whether vegetative or sentient, are immediately dependent on the nervous system; that some peculiar and refined species of fluid, which they regarded as identical with the animal spirits of the ancients, was *secreted by the brain, and conveyed to all parts of the body through the nerves.* It must, however, be confessed, that the *neuro-physiologists* never explained what enables the brain to secrete; how the solids are formed from the blood; what endows the blood with the power of vitalizing all the organs; in what way the eggs of animals are hatched by nervous influence; nor how the life and growth of vegetables, including many of the lower orders of animals that have apparently no nerves, are sustained.

Yet the celebrated Cullen represents the brain as necessary to the action of the vital principle, and the primary source of animal motion, whether voluntary or involuntary. He further maintained that all diseases should be referred to some preternatural condition of the nervous system; that cold, miasmata, fatigue, the depressing passions, &c. diminish the vital energy of the brain, and through it that of all the other organs, causing debility and a spasmodic state of the capillary vessels, as in the cold stage of fevers. He further maintained that *the temperature of animals*

is in proportion to the quantity of their life, or nervous energy. Yet he never explained how animal heat is generated by respiration; how diminished during the cold stage of fever, and increased during the hot; why fever is attended with nausea, headache, pains in the back, limbs, &c.; nor in what way spasmodic diseases arise from derangement of the nervous system. But I shall endeavour to make it clear in the following pages, that the brain is no more the origin of animal motion, than the rudder of a steam-vessel is the cause of its moving power; that as the object of the one is to guide the direction of the vessel, so it is the office of the other to generate ideas, or endow the living machine with sensation, intelligence, volition, &c.

In accordance with the Newtonian doctrine, that all the molecular changes of matter are owing to the innate powers of attraction and repulsion, Haller referred the phenomena of life to *irritability* and *sensibility*, the first of which was regarded as an inherent property of the muscular fibre, and termed *vis insita;* while the other was supposed to reside in the medullary tissue, and was called the *vis nervosa.* But if the muscular and nervous systems be not duly supplied with living blood, the *vis insita* and the *vis nervosa* can have no existence; nor can they be supported by the blood, unless the latter be vitalized by respiration. It is therefore evident that these fundamental properties of life are derived from the atmosphere, and not inherent in any part of animal bodies, whether solid or fluid.

With the most distinguished philosophers of ancient and modern times, it was maintained by John Hunter,

that all the phenomena of animal life are governed by an independent principle, which he termed the *materia vitæ*, and sometimes the *architect* or *organ builder*. But so far was he influenced by the neuro-physiology of Hoffman and Cullen, that in his *Treatise on the Blood*, he confounds it with the hypothetical nervous fluid, and even with the medullary substance. He says, "I consider that something similar to the materials of the brain is diffused through the body, and even contained in the blood, between which and the brain a communication is kept up by nerves: I have therefore adopted terms explanatory of this theory, calling the brain the *materia vitæ coascervata;* the nerves *cordæ internunciæ;* and that which is diffused through all parts of the body, the *materia vitæ diffusa.*" (*Page* 89.) But, again: he observes that breathing seems to communicate life to the blood, which imparts it to all the other organs; that as the brain and nerves are composed of the same tissue, it is presumptive proof that nothing material is conveyed from one to the other; but that sensations and volitions are only a species of nervous action. So contradictory and unsettled were all his notions on this important subject, that he again represents "the stomach as the seat of the *materia vitæ*, and thereby the organ of universal sympathy;" to which he referred "the sensations of heat and cold that attend many diseases." In another place he confounds the organizing principle with "a certain species of motion," in the same way that Bacon, Rumford and others, confounded heat with motion; or as the disciples of Sir Isaac Newton have confounded the cause of attraction and repulsion with *mechanical force*. To

complete the problem of contradictions, Hunter finally observes, that "life is a *property* we do not understand."

In accordance with the doctrine of Cullen, (who rejected Dr. Black's theory of respiration as the exclusive source of animal temperature,) Hunter maintained that "*the degree of heat in animals is in proportion to the quantity of their life.*" (*Phil. Trans.* vol. lxvi.) But it might as well be said that the degrees of heat throughout the earth, from the equator to the poles, are in proportion to the quantity of animal and vegetable life. Had this great anatomist known that all the physico-chemical and vital operations that make up the history of our planet are directly in proportion to the heating power of the sun, he would have recognized caloric as the cause of motion, and as the grand instrument of the Deity in all the revolutions of matter—from the formation of mountains to the aggregation of crystals, and the more complicated organization of living bodies. Or had he known that the vital energy of animals is directly in proportion to their standard healthy temperature, he would not have inverted this fundamental law of physiology.

In the observations of Hunter on the animal economy, he recommends to the attention of philosophers a comprehensive inquiry into the laws of heat, as connected with all the operations of nature. And he observes in his Lectures on the *Principles of Surgery*, that "heat must be regarded as one of the first principles of action in nature, which unlocks matter, and allows it to act according to its natural properties; that it is congenial with the vital principle, which

owes its vigour to a due supply of heat; that it is a sign of strength in the constitution, whereas coldness arises from weakness of the whole constitution."* And Broussais observes, that "caloric is the first and most important of all stimulants; that if it ceases to *animate* the economy, others lose their influence over it; that all the preservative, recuperative and sanative phenomena cease; and that caloric brings into play the unknown power which constructs the organs." (*Pathol.*, p. 110.) Dr. Dowler, in fact, seems to have adopted my own views, since he represents caloric as the great motor of the universe, and that it ought to be studied in preference to hypothetical agents or vital metaphysics. (*West. Journ. of Med.*, June, 1844, p. 447.) But I have shown that heat is not only the agent which unlocks matter, but that it is the great bond of union, without which matter could have no power of action.

When commenting on Hunter's theory of life, Mr. Abernethy observes, that the widely extended research into all the phenomena of nature which the subject requires, is more adapted to an ancient Greek philosopher, than to one of the present day. He then declares himself at "a loss to know what chemists now

* Following in the footsteps of Hunter, Sir Gilbert Blane observes, that "the combination of heat with the *conservative principle*, forms the main constituent of simple life." (*Medical Logic.*) But, like the *vis insita* of Haller, the *vis medicatrix naturæ* of Hoffman and Cullen, the *excitability* of Brown, the *sensorial energy* of Darwin, and the *nisus formativus* of Blumenbach, the conservative principle is a mere refuge for ignorance in regard to the physical cause of all the vital functions.

think respecting heat—whether they conceive it to be a distinct species of matter, or mere motion; and that in this state of perplexity he could not advance one step farther than Mr. Hunter had led him." Alas! that great man left the theory of life in almost as much obscurity as the chemists have left that of heat, light and electricity; for, notwithstanding his numerous experiments on the blood, he never explained the cause of its coagulation and conversion into the various tissues.

Since the discovery of oxygen by Priestley and Scheele, Girtanner, Blumenbach, Richerand and many other physiologists in different parts of Europe, including Dr. Southwood Smith and Dr. Holland, have maintained it to be "the life-sustaining principle of the atmosphere." But it is absolutely certain that oxygen exerts no influence whatever in maintaining the functions of animal life, unless it undergoes a chemical change in the lungs, by which caloric is evolved and united with the blood. Besides, the quantity of life throughout the earth is not in proportion to the amount of oxygen, which is even more abundant in the polar regions than in the climes of perpetual summer. It would, therefore, be a waste of time to dwell on the absurdity of regarding oxygen as the organizing principle independent of caloric.

When it was found that electricity is capable of causing the muscles of recently killed animals to contract, philosophers began to imagine that this agent was identical with the unknown nervous fluid, and generated in the brain, which some have represented

as a galvanic battery.* Mr. Abernethy fancied that it was the *materia vitæ* of Hunter; while Lamarck supposed that the vital principle was composed of electricity and light. But it is not in the form of electricity that the solar fluid warms and vivifies the world. Nor is it in the form of electricity that solar heat maintains the fluidity of the ocean, the mobility of the air, the transformations of chemistry and the growth of plants; or that animal heat maintains the fluidity of the blood, the action of the heart, brain and all the other organs. As I have already proved that caloric is the active principle in light, and that all the different forms of electricity are modifications of this universal principle, it is needless to dwell longer on the electrical theory of life.

* In a recent work on the *Principles of Medicine*, by Dr Billing, the author maintains that "the contractile power of the different tissues is called into action by nervous influence, generated in the cineritious portion of the nervous system, and conducted by the white medullary part to all the organs; that it is *analogous to, or depends on, if not identical with the electrical principle, or fluid, whatever that may be;* that the energy of parts depends on a something communicated to them by the nerves, in conjunction with the brain and spinal marrow; causing the deposition of new, and the absorption of old matter, which keeps up a slow combustion, and produces an extrication of caloric." (*Pages* 17 and 20.) In other parts of the same work, he contends that all febrile diseases have their seat in the cineritious portion of the brain and nerves; and that convulsions have their seat in the white or medullary part of the same system, whether arising from excessive cold, irritation of the bowels, the action of narcotic poisons, the virus of a rabid animal, emotions of fear, wounds, &c.; that hydrophobia is a leaven which poisons the nervous system; and that the smallpox virus may produce its effect by some *chemical* or *electrical* action, positive or negative, on the nervous tissue.

From the earliest dawn of science in India, Chaldea, Egypt and Greece, down to this period, the organizing principle was almost universally regarded as an independent, ethereal and refined substance. The same doctrine was held by the most distinguished fathers of the church, who maintained that the soul, or animating principle, whether it inhabit the body or not, is of a corporeal nature. It was the opinion of St. Austin, that whoever denies this, reduces the soul to a non-entity, and thus virtually takes away the proofs of its existence. In his treatise, *De Quantitate Animæ*, he reasons thus:—"Take away extension from bodies and they will be nowhere, and if they are nowhere, they will not be at all." But since the publication of Sir Isaac Newton's *Principia*, many physiologists have maintained that there is no such thing as a primary and efficient cause of power in nature, distinct from the phenomena produced; that cause and effect are resolvable into the mere antecedence and sequence of events; or that what is a cause in one case, is an effect in another. Dr. Thomas Brown observes, that men have not been able to discover the cause of gravitation, cohesion and chemical affinity, because there is none except the inherent tendency of masses and their constituent particles to approach one another. But it might as well be said that there is no other cause of steam-power than the inherent tendency of water to expand into the gaseous form, which is absurd, and contradicted by all experience. Besides, if it be true that caloric possesses the power of moving itself, and of generating motion in other bodies, it must be endowed with the essential attributes of a

primary cause. And if when deprived of this principle the particles of matter become passive and motionless, it is clear that, without its agency, they could have no power of approximating, or of receding from each other.*

Yet we are told by many of the most distinguished modern physiologists that, as Newton succeeded in resolving nearly all the phenomena of nature into the inherent properties of matter, there is no necessity of resorting to the agency of any distinct principle as the primary and efficient cause of animal motion. In accordance with this view, Bichat defines "life as the sum of the functions that resist death,"—Cuvier, as "the combined result of all the organic functions,"—and Richerand, as "the assemblage of the properties and laws that govern the animal economy." He says: "Le mot de principe vital, force vital, &c. n'exprime point un être existent par lui même, et indépendamment des actions par lesquelles il se manifeste: il ne faut l'employer que comme une formule abrégé, dont on

* So far as it was the object of Brown to guard men against the error of assuming the existence of some occult and immaterial cause of power in bodies, of which experience affords no proof, he was clearly right; for it must be admitted that all causes, whether material or spiritual, that exist in nature, must be a portion of the divine work. Newton carried this doctrine so far as to maintain the materiality of the *Great First Cause;* for, said he, "there can be no virtue without substance." (*Opticks*, book iii.)

But without transcending the limits of the human mind, it may be safely affirmed, that whoever denies the existence of any cause of attraction, repulsion and animal motion, distinct from the phenomena produced, not only rejects the evidence of reason and the common sense of mankind, but involves the whole theory of nature in profound obscurity.

se sert pour désigner l'ensemble des forces qui animent les corps vivans, et distinguent de la matière inerte." (*Nouveau Elémens de Physiologie*, tome i. p. 80.) As to Emanuel Kant's definition of life, it is characterized by the vagueness of transcendentalism in general. "Life," says he, "is an internal faculty producing change, motion and action." He might as well have admitted with Mr. Hunter, "life is a property that we do not understand."

Here, then, as Mason Good observes, "we have not only the employment of terms that have no meaning, but properties, laws and powers without any source,—a superstructure without a foundation,—effects without a cause."*

Similar views have been expressed by Magendie, who thinks that "physiology is now in the same condition that natural philosophy was before the time of Newton, and only waits until a genius of the first order shall arise to unfold the laws of vital force, as Newton did those of general physics." More than an hundred other writers might be quoted who have denied the existence of a vital principle, as maintained by Hippocrates, Aristotle, Galen, Celsus, Paracelsus,

* The truth is, that laws necessarily presuppose the existence of an agent; for they are merely the mode in which it produces effects in a regular or uniform manner. And it might as well be said that "murder is the act of murderously killing a man;" that "death results from a want of vitality;" that "opium induces sleep by means of a dormitive property;" that "the heart contracts by means of a pulsific virtue;" or that all the movements of nature are the sum of the powers that prevent it from falling into a state of quiescence; as that "life is the sum of the functions that resist death." It would be an abuse of reason to refute such vagaries.

Servetus, Harvey, Van Helmont, Borelli, Perrault, Stahl, Hunter, Lamarck and Abernethy; while a large majority of modern philosophers have, with an equal disregard of the clearest evidence, rejected the materiality of caloric, electricity and light.

Dr. Prichard objects to the doctrine of a subtile fluid as the cause of vital action, because he cannot conceive how it could produce the wonderful phenomena of animal motion, sensation and thought, unless endowed with intelligence. This in reality was the opinion of Hippocrates, Galen, Seneca and Virgil, who maintained that all the operations of nature were governed by the immediate agency of mind—"mens agitat molem." The same doctrine was taught by Paracelsus, Van Helmont, Harvey and Stahl, who, with the ancients, seem to have identified the active principle in nature with the eternal mind of the universe.

The celebrated Baxter denied the existence of a subtile fluid as the cause of crystallization and planetary motion, because he could not conceive how it could produce such effects, unless it knew what it was about. (*Immateriality of the Soul*, p. 117.) He therefore maintained the vacuum of space, and referred all the phenomena of nature to the immediate agency of the Deity.

From the foregoing brief history, we may readily comprehend why no modern system of medicine has maintained its credit above fifty years. Like the house in the parable, that was built upon the sand, they have been defective at the very foundation, which, not being able to uphold the superstructure,

they have gradually crumbled away, to be replaced by others destined to share the same fate.

The observation of Bacon is no less applicable now than it was two hundred years ago:—"Medicine is a science which hath been more professed than laboured, and yet more laboured than advanced; the latter having been, in my judgment, rather in circle than in progression; for I find much iteration, but small addition." Mr. Whewell affirms, in the last chapter of his *Bridgewater Treatise*, that "we have yet to begin to learn all that we are to know concerning the ultimate laws of organized bodies." And he observes, in his late *History of the Inductive Sciences*, that "many anatomical truths have been discovered, *but no genuine physiological principle;* that the notion of life, and of vital forces, is still too obscure to be steadily held; and that we cannot connect it distinctly with severe inductions from facts; that we can trace the motions of fluids, as Kepler traced the motions of planets; but when we seek to render a reason for these motions, like him we recur to terms of wide and profound, but mysterious import—to virtues, influences and undefined powers." (Vol. iii. pp. 404 and 431.)

CHAPTER II.

"Nil turpius physico, quam fieri sine causa quidquam dicere."—Cicero.

"The ultimate purpose of our researches is to penetrate and lay open the secret springs by which the great system of organization, termed nature, is maintained in a state of perpetual activity." —Lawrence.

The prevalent doctrine of modern physiologists, that the phenomena of life are wholly distinct from those of inorganic matter, has arisen from our imperfect knowledge in regard to the primary physical cause of motion throughout nature; and is refuted by the fact, that the amount of vegetable life on our planet, like all the mechanical and chemical transformations that modify its surface, is directly in proportion to the quantity of caloric which it receives from the sun. For we have already seen that as the amount of evaporation and rain, the magnitude of rivers, the number of volcanos and the elevation of mountains, diminish from the equator to the regions of lowest mean temperature; so do the number, variety and magnitude of organized beings. Let us then reject the notion of Bichat, that "physics are not accessary, but foreign to the science of physiology." (*Life and Death*, p. 83.)

It was observed by the learned Tiedemann, that

"the final cause of vital force, like that of attraction, repulsion, gravitation, cohesion and chemical affinity, is a secret whose profundity we shall never be able, from all appearances, to reach." (*Compar. Physiology*, p. 193.) But we have seen that without the union of caloric with the particles of ponderable matter, they could have no powers of approaching to or of receding from each other; and that the entire extinction of solar radiation, if such a thing were possible, would put an end to the sublime revolutions of the heavenly bodies, together with all that is beautiful and glorious in the visible creation.

The celebrated Müller observes in a late work on the *Elements of Physiology*, that our knowledge of the vital principle is not more imperfect than it is with regard to the nature of caloric, electricity and light; and that the cause of crystallization is no less difficult to comprehend than that of organization. But I have shown that caloric is a self-moving agent and the active principle in light, as in every form of electricity; that it depends wholly on the amount of caloric in bodies whether they exist in the solid, liquid or gaseous state; and that the crystalline form of salts, rocks, &c. is greatly modified by the temperature at which they were formed, as in the phenomena of *dimorphism*. Nay more, that there are many bodies composed of *the same elements in exactly the same proportions*, which exhibit perfectly distinct properties when united with different proportions of the same active principle that transports their particles from one place to another, and arranges them in symmetrical forms; that gallic acid is converted into pyro-gallic acid by the addition

of heat alone; and the latter into another distinct substance by a further addition of caloric, as in the formation of isomeric bodies.

It has been asserted by innumerable writers on physiology, that the phenomena of life are as far removed from those of ordinary chemistry as the latter from mechanics. But the Great Architect of the universe has so completely connected all the operations of nature together, that it is often difficult to draw the boundary line between mechanical, chemical and vital action. The mechanical force of steam is generated by the chemical union of caloric with the particles of water, to the expansion and contraction of which we are indebted for all the phenomena of evaporation and rain, the nourishment of plants and the sustenance of animal life.* The circulation of sap through the vessels of plants is no less the result of attraction than the absorption of water by a sponge, or its elevation in the capillary tubes of dead matter; but with this difference, that the force is much greater in living vessels, owing to their extreme minuteness, compared with artificial tubes. The conversion of sap into organic molecules, and the latter into woody fibre, bark, leaves, flowers, fruits and different secretions, is no less the result of attraction than the generation of water, salts, rocks and other chemical compounds.

The first process of germination consists in a chemical fermentation in the seed, by which a portion of

* And if it be true, as there is every reason to suppose from analogy, that solar light, like that of a lamp or common fire, is generated by combustion, all the phenomena of nature must be referred to chemical action.

its substance is converted into sugar and carbonic acid, while another portion is changed into living organic molecules, that are arranged in symmetrical order, corresponding with the parent type from which it sprung. The generation of confervære and animal infusoria, during the putrefaction of organic matter, is no less the result of attraction than the conversion of sap into trees, and blood into the structure of animals, whether produced from seeds and eggs, or without the concurrence of parents, as maintained by Needham, Priestley, Ingenhouz, Monti, Wrisberg, Tiedemann, Müller, Treviranus and many other distinguished philosophers. The same is true of the different species of entozoa found in the liver, brain, eyes, veins and other parts of warm-blooded animals, which seem to be formed by the immediate combinations of morbid secretions in the parenchyma of their organs, according to the observations of Pallas, Müller, Treviranus, Rudolphi and many others. But caloric is no less essential to fermentation, germination, circulation, nutrition or the generation of microscopic plants and animals from the proximate constituents of dead organic matter, than to the combinations of ordinary chemistry.

So far as digestion depends on the solvent power of gastric juice, it is a chemical process, by which dead matter is converted into chyme. And that it is owing chiefly to the agency of caloric, would appear from the fact, that the digestive function in all animals is performed with a rapidity exactly in proportion to the amount of their respiration and mean healthy temperature, being greater in birds than in mammalia,

and very much greater in both than in cold-blooded animals, which require many days, and some of them several weeks to digest a single meal. We also learn from the experiments of Spallanzani, that the digestive power of gastric juice when taken from the stomach increases from 50° to 120° F.; and from the late researches of Dr. Beaumont, that when put in vials and kept at the temperature of 100°, it converted food into a species of chyme that could scarcely be distinguished from what was formed in the stomach, but required a longer time to produce the effect. The fact is, that cooking may be regarded as the initiatory process of digestion; for it is not only the softening of raw animal and vegetable matter by the action of fire, and thus preparing it for entering into new combinations in the living body, but greatly changes its taste, odour and other sensible properties.

The all-important function of respiration, so essential to animal life, is, strictly, a chemical process, by which a portion of atmospheric oxygen unites with carbon to form carbonic acid, with an evolution of caloric. Who then can say at what precise point the operations of chemistry are merged in the affinities of life, as in germination, spontaneous generation, the nourishment of plants, &c.; or when the latter terminate in the actions of ordinary chemistry, as during the ripening of fruits?

There is nothing more calculated to excite our admiration of the infinite wisdom by which the universe is governed, than the intimate relation that exists between all its physico-chemical and vital operations. By the mechanical diffusion of water through the

atmosphere, organized bodies are supplied with the greatest part of their substance. The carbonic acid generated by chemical action during the processes of combustion, fermentation and the respiration of animals, affords nourishment to plants—being decomposed in the tissue of their leaves, where crude sap is converted into cambium by the evaporation of water and the absorption of carbon; then into starch, sugar, oils, &c., which in their turn become the appropriate nourishment of animals. It was justly observed by Sir Charles Morgan, that "the distinctions which the subtilizing genius of man has invented to separate and to isolate, are contradicted and deranged at every new step of successful investigation." (*Philosophy of Life*, p. 62.)

ULTIMATE ELEMENTS OF ORGANIZED BODIES.

Among the sixty-two undecompounded bodies, in dependent of the imponderables, that form the crust of the earth, nineteen have been found in plants and animals, ten of which are non-metallic, and nine metallic; viz., oxygen, hydrogen, nitrogen, carbon, phosphorus, sulphur, chlorine, iodine, bromine, fluorine, potassium, sodium, calcium, magnesium, silicium, aluminum, with the more ponderous metals, iron, manganese and copper. *But the most remarkable circumstance connected with the chemical constitution of organized bodies is, that they are composed chiefly of the most light, active and mobile species of matter, such as oxygen, hydrogen, nitrogen and carbon, the three first of which are always found in the gaseous state, when not*

united chemically with other bodies; while their elasticity is such that no mechanical pressure has ever yet been sufficient to overcome it. Hence it is that the atmosphere, and the waters that are elevated from the ocean, which are composed of these elements, are in a state of perpetual motion, circulation and chemical combination with other bodies.* These, with carbon, are the basic constituents of organized bodies; for the sum of the remaining fifteen does not exceed two or three per cent. And that the staminal elements of organic matter contain a larger amount of caloric around their particles than an equal weight of any other known bodies, might naturally be inferred from their tendency to assume the fluid state, their highly inflammable properties, their general activity, and from the enormous amount of heat evolved during their combustion.

On the other hand, the leading characteristic of the mineral world is, that it is composed chiefly of metallic bases, which are not only the most dense and gross, but the most inert descriptions of ponderable matter. The consequence of which is, that at all ordinary temperatures of the atmosphere, they remain solid and quiescent, while "the moving waters and the invisible air," are continually circulating throughout the earth, as if impelled by some spiritual agent. But if

* It was long ago said by Aristotle, that the lightest descriptions of matter are the most perfect, and partake the nature of forms. As a proof that this is actually the case, it may be observed that the variety of organized species, which are composed of the lightest elements, is far greater than that of mineral bodies, and they possess a far more complex structure.

submitted to the influence of intense heat, the most refractory bodies are changed to the fluid state, (the essential condition of which is mobility,) and acquire the power of entering with great rapidity into new combinations, as in the regions of subterranean chemical action, where the rocks that form the solid mountains of the globe are aggregated,—and among the ruins of which have been discovered nearly all the precious metals and gems, including the rich and sparkling diamond. The metallic elements, united with various proportions of oxygen, hydrogen, nitrogen, carbon, &c., constitute the massy frame-work of the earth; but they are wholly incapable of forming organic compounds, and of executing the more elevated functions of living matter. It is therefore obvious that there is a broad line of demarcation between the chemical constitution of mineral and organized bodies.

Another fundamental difference between them is, that, with the exception of oxygen, hydrogen, carbon and nitrogen, all the other elements of ponderable matter are capable of entering into simple binary combinations only; whereas the ultimate principles of organic bodies seem to possess the additional power of forming ternary and quaternary compositions. Thus oxygen with hydrogen produces water; with sulphur, phosphorus, nitrogen, carbon, &c., it forms acids which are single binary compounds.* With calcium, sodium,

* Oxygen enters into the composition of nearly all bodies. It constitutes one-fifth of the atmosphere, eight-ninths of all the waters, and about one-third of the solid earth. But as in the latter case it is chained down in a state of chemical combination with metallic and other gross matters, its active powers are kept in

potassium, &c., it makes alkalies that are also binary combinations, which, on uniting with the above acids, form neutral salts, that must be regarded as double binary compositions; while the union of the same acids with simple bodies, such as the pure metals, gives a third order of binary compounds, according to Berzelius.

But in the formation of the simplest plant, it has been found that at least three elements, oxygen, hydrogen and carbon, are united together in a direct manner, without any previous binary combination; and that the various tissues of all animals (if we except the very lowest species of zoophytes, the real character of which is doubtful,) are formed by the immediate union of the same elements with nitrogen. From the ternary and quaternary combinations of these active principles in various proportions, are generated all the diversified organizations that make up the living world, as shown by the analytical researches of Thenard, Gay-Lussac, Berzelius, Prout, Thomson, Saussure, Berard, Chevreul, Ure and others. (*Tiedemann's Comparative Physiology*, pp. 6, 7.)

But in addition to the power of oxygen, hydrogen, carbon and nitrogen, to form ternary and quaternary compounds, it is worthy of special notice, that many more atoms of the same elements unite together in forming organic combinations than are found in those of inorganic bodies. For example, water is composed

abeyance. It also forms about seven-eighths of animal bodies, and above two-thirds of plants, as may be readily ascertained by a reference to their elementary composition, and the relative quantities of water in each.

of one atom of oxygen to one of hydrogen; carbonic acid, of carbon one atom to two of oxygen; and so of innumerable other binary compounds; whereas the acid, saccharine, oily and resinous constituents of plants, are generated by the immediate union of many oxygen, hydrogen and carbon atoms. Starch is composed of twelve atoms carbon, ten of oxygen, and ten of hydrogen; sugar of twelve atoms of carbon, eleven of oxygen, and eleven of hydrogen; while the oil of peppermint consists of carbon atoms ten, hydrogen ten, and oxygen one. The resins and fixed oils contain still higher numbers of the same atoms, as may be seen by referring to *page* 148 of the First Book, where it has been shown that this constitutes the principal difference between the volatile and more tenacious compounds of organic matter. From which it is probable that the quaternary unions of oxygen, hydrogen, carbon and nitrogen, to form the proximate constituents of the blood and solid tissues of animals, contain still higher numbers of atoms of the same elements. So that whether the affinities of life be owing to the same physical cause which governs those of inorganic matter or not, the former evince at once a far more complex and refined mode of operation. Hence the beautiful remark of Kielmyer, as cited by Tiedemann, that crystallization represents in some degree the simple elements of geometry; while in the production of organized bodies, nature has employed a high geometry.*

* It may here be observed that saccharine bodies, including gum, starch, lignin, &c., are formed by the union of oxygen and hydrogen in the proportions that form water, with carbon; that

Owing to the more complex affinities by which the elements of organized bodies are joined together, they have a greater tendency to undergo what has been called spontaneous decomposition, than the binary combinations of inorganic matter. And it would seem to be a general law of nature, that *the force with which bodies cohere together, is inversely as the number of elements and atoms of which they are composed.* For example, water is more difficult to decompose than the deutoxide of hydrogen; carburetted hydrogen, than bicarburetted hydrogen; and the latter than etherine. In like manner, the protoxide of nitrogen is more difficult to resolve than the deutoxide; and so on till we come to nitric acid, which is composed of five atoms oxygen to one of nitrogen, and may be decomposed with great facility. But I have shown that the quantity of caloric around the particles of alcohol, ether, nitric acid, &c., is in proportion to the number of atoms that enter into their composition, *cœteris paribus.* It is therefore not true, that the disposition of organized bodies to run into new combinations is owing merely to their elements not being united in different proportions, or to their not being saturated, as maintained by Tiedemann and others; for the elements of sugar, alcohol and many other similar compounds are as completely saturated as those of water, carbonic acid, or the earths and alkalies, which are so difficult to decompose.

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the same elements with oxygen in excess form acids; while with hydrogen in excess, with respect to oxygen, they afford oily and resinous compounds. Yet there is a large class of acids that contain no oxygen, such as the hydrocyanic, the hydrochloric, &c.

Corresponding with the simple binary composition of minerals, they are of uniform structure throughout; and when once formed, their individual existence depends on the repose of their particles. What they are when first aggregated, they remain until destroyed. They may be enlarged by accretion, and diminished by attrition, but they have no organs of nutrition, secretion, or reproduction; no origin by birth, no renewal of their composition, and no termination by death. Being composed of the more ponderous elements, or binary combinations of them, they are held together with great force, and endure for a much longer time than trees, which consist of ternary combinations of more active elements. For the same reason, animal bodies that are formed of three elastic gases, united in various proportions with carbon, are more volatile and destructible than wood, after the affinities of life have ceased. In other words, minerals are more solid and fixed than plants, because they are formed of more gross and inert materials; while trees are more solid and durable than the animal tissues, because the first are composed chiefly of water, with carbon, and the latter of air, water and carbon.

So essential are fluids to the existence of organized bodies, that they constitute nearly the whole of their substance during the embryotic state, especially in the egg and fœtus of animals. But the proportion of fluids to that of solids, varies in different species, and at different periods of their growth, being about ten to one during early life in the human body, and six to one in old age. According to Richerand, they are as three to one in trees; but they are much more abundant in

the annual and more succulent plants, as also in the newly formed parts of trees; while it is worthy of notice, that the affinities of life are always most active in those parts which receive the greatest amount of fluids, such as the medullary and muscular tissues of animals, and the soft vascular structure of plants; but that the movements of life are slow and feeble in the hard woody fibre, and almost wholly absent in the earthy matter of bones. *Fluidity*, then, which is only another name for *mobility*, is absolutely essential to the manifestations of life.

According to the latest analyses of human venous blood, it has been found to consist of about 790 parts of water in 1000, and the remainder of albumen, fibrin, colouring matter, oily and saline ingredients. From which it is obvious that as water is composed of eight parts by weight of oxygen to one of hydrogen, and also forms about one-third of the organized part of the blood, oxygen must constitute by far the greater proportion of its substance; the remainder being carbon and nitrogen, with nearly one per cent. of saline matter.

From the ternary and quarternary combinations of oxygen, hydrogen, carbon and nitrogen, organic molecules are generated, which form the proximate constituents of all living bodies, whether fluid or solid, from the simplest plant or gelatinous animalcule up to man. They have been found in the blood, chyle, chyme, milk, fat, saliva, bile, pancreatic and gastric juice, the seminal fluid, the yolk and albumen of the egg, in all animals; in the sap of plants, and much more abundantly in the cambium, after it has been exposed to the

influence of solar warmth while circulating through the leaves. They have also been discovered in the albumen of farinaceous seeds and bulbous roots, the cells of flowers, and the embryo while forming, according to many accurate observers, cited by the learned Tiedemann. As might naturally be supposed, these globules, as they have been termed, vary in form, colour and magnitude, according to the species to which they belong, and the office they are destined to fulfil.

By the arrangement of organic molecules, in series and aggregates, the primary tissues of all living bodies are generated, in accordance with laws no less fixed and definite than those of crystallization. The lowest species of plants and zoophytes, such as fungi, lichens, algæ and the gelatinous animalcules, are composed chiefly of cellular tissue, which in the higher orders of plants is expanded into ligneous fibre, bark, leaves and flowers. The cellular tissue also enters so largely into the composition of the more perfect animals, that it has been often represented as the scaffold of all the organs, and the mould in which their particles are deposited. The osseous, cartilaginous, fibrous, vascular, serous, dermoid and mucous membranes, are all regarded as modifications of this primary tissue, which is formed chiefly of albumen, arranged in lamellæ and fibres variously interlaced, so as to constitute a net-work of cells, that communicate with each other throughout the body.

But as the elementary composition of animals is more complex than that of plants, they present a more diversified system of organization, if we except the

lowest species of zoophytes, which so nearly resemble the simpler microscopic plants, that some physiologists have maintained their mutual convertibility into each other. For example, in addition to cellular tissue that forms the basis of plants, and the principal portion of the higher animals, the latter are composed of *muscular and nervous* tissues, by which they are endowed with the powers of locomotion, perception and consciousness. The muscular fibres are formed of fibrin, the particles of which are arranged in lines that resemble rows of globules under the microscope; while the nervous tissue is composed of albumen, and certain oily matters that contain much hydrogen, and a little phosphorus, forming an infinite number of exceedingly minute and delicate tubes. (*Müller's Elements of Physiology*, vol. i. p. 599.)

By the union of these three primary tissues in various proportions, the different complicated organs of the animal fabric are built up, as the heart, stomach, intestines, liver, pancreas, kidneys, muscles, ligaments, tendons, cartilages, membranes, bones, &c.; all of which are generated from the albuminous, fibrinous, oily and saline constituents of the blood; which is formed by the immediate union of oxygen, hydrogen, carbon and nitrogen, into quaternary combinations. Most of the fluids secreted by animals, such as gastric juice, bile, mucus, pancreatic and seminal liquor, are also quaternary compounds. But they also secrete several combinations that are ternary, as the sugar of milk and urine, fat, resin and the volatile oily matters termed civit and castor. On the other hand, there are many plants that contain more or less nitrogen, which is abundant

in mushrooms, and in the vegetable salifiable bases, morphine, narcotine, veratrine, solanine, delphine, emetine, quinine, cinchonine and many other like compounds. From which it is obvious, that the more complicated organization of animals than of plants, is not owing merely to the greater complexity of their elementary composition, as will further appear hereafter. Yet there cannot be a doubt, that the structure and functions of all organized bodies are determined by the chemical constitution and fundamental properties of their ultimate elements, which are modified by every increase or diminution in the quantity of caloric around their atoms.

The great question that lies at the very foundation of organic chemistry is, whether the power of forming organic compounds, with the aptitude for renewing their composition by assimilation and elimination, be owing to the same cause which governs the affinities of dead matter, or to some peculiar principle of a totally distinct nature, as maintained by Berzelius, Tiedemann, Müller and nearly all the most distinguished physiologists of the present day. Nothing but an earnest appeal to nature and a careful examination of facts can resolve this difficult problem.

The learned Tiedemann observes very justly, that the difficulty of explaining the phenomena of life by the laws of physics may be owing to our imperfect knowledge of natural phenomena in general. But Müller contends, that "the power by which the elements of organized bodies are united into ternary and quaternary compounds in opposition to the laws of chemistry, is, without doubt, a peculiar force, or im-

ponderable matter, unknown in inorganic nature." Yet he admits in another place, that the cause of crystallization is not less profoundly hidden than that of organization. (*Elements of Physiology*, pp. 22, 251.) That the power of oxygen, hydrogen, carbon and nitrogen, to form the proximate constituents of living bodies, is owing to the fundamental properties of these elements, would appear from the fact, that no others are capable of entering into ternary and quaternary compositions; in short, that no plant or animal was ever formed or nourished by any other elements. And that the tendency of dead organized bodies to undergo decomposition, is owing to the same active principle that enables these elements to form ternary and quaternary combinations, is proved by the circumstance that this tendency is augmented by every addition of caloric, which I have shown to be not only the universal bond, but the great decomposer of all matter.

During the decomposition of organized bodies under the influence of a summer temperature, a portion of their substance enters into binary compounds of water, carbonic acid and ammonia. But during this process, another portion of the same elements unites to form the simplest species of microscopic plants and animalcules, without the concurrence of parents, seeds, eggs or the addition of any other principle than was concerned in the generation of water, carbonic acid, &c.*

* It is related by Sharon Turner, that in boring for water near Kingston-upon-Thames, some earth was brought up from a depth of 360 feet; and though carefully covered with a hand-glass to prevent the possibility of any seeds being deposited on it, was yet in a

And as it has been shown that the form of crystals depends on the nature of their atoms, modified by the temperature at which they are aggregated, so has it been observed that the specific character of infusoria, generated during the fermentation of albumen, fibrin, starch, gluten and other organic compounds, varies according to the different species of matter employed.

It is also said, that there is a progressive advance in the productive power of the infusion, which at first produces animalcules of the smaller kinds, that afterwards become gradually larger and more complex in structure; that when the quantity of water is small, and the organic matter abundant, there is a predominance of vegetable production; but that when there is much water, animalcules predominate. It is therefore highly probable, that if all the plants and animals that now inhabit the earth, together with all their seeds and eggs, were annihilated, other orders, genera and species, would gradually arise, under the influence of existing laws. The idea that every new creation of organic beings, requires a special or miraculous

short time covered with vegetation. (LARDNER, *Hist. of the Earth*, vol. i. p. 210.) If in this case, the vegetation sprang from seeds, they must have been preserved in a damp soil for more than a million of years, which is incredible. But does any one suppose that the aboriginal generation of plants is more miraculous than their perpetuation by sexual intercourse? or that different agencies are required to effect both results? Is it strange that our mother earth which gives birth to all things under the influence of the prolific sun, should cause herbs to spring from her fruitful bosom without seed? If not so, how did plants and animals begin their existence before there were any seeds or eggs?

feat of the Deity, is equal to saying that the universe requires new modifications of the plan on which it was originally constructed, and therefore is imperfect.

Those simple organizations termed entozoa, generated in the parenchymatous substance of many animals, without the visible existence of any parents, eggs or germs, also vary according to the nature of the animal, and even of the organ in which they are formed.* Nor is there anything more mysterious in this, than in the ordinary process of generation, only that we are more accustomed to the latter; or that specific contagions should be generated by certain combinations of filth and vitiated animal secretions, as in gonorrhœa, lues venerea, smallpox, &c., that have the power of propagating themselves in a mode analogous to the production of fermentation by yeast; which, according to the observations of De la Tour,

* It is said that twelve different species of entozoa have been found in man, six in the alimentary canal and its appendages, one in the lungs, one in the brain, one in the eyes, one in the muscles, one in the kidneys, one in the ovaries and one in the skin; while in the several organs of the sheep, nine species have been discovered; eleven in the ox; nine in the horse, hog and fox; and eight in the hare. They have been found in birds, reptiles, fishes, crustacea and mollusca. (See *Fletcher's Rudiments of Physiology*, part ii. p. 12.)

They have also been found in the embryons of these animals; from which it is maintained by Pallas, Müller, Werner, Bloch, Göeze, Braun, G. R. Treviranus, Rudolphi and others, that they are the products of non-assimilated matters, or morbid productions formed in the humours or parenchyma of the organs, in a mode resembling the generation of infusoria during the fermentation of organic matter. (*Tiedemann's Comp. Physiology*, p. 40.)

is composed chiefly of organic molecules that have the faculty of multiplying themselves in all fermentable matters.

Should it be objected that such molecules, like the different species of moulds, confervæ and animalcules, can be generated only from matter that has been once organized, I answer that the elements of oxygen, hydrogen, carbon and nitrogen, wherever they exist, are capable of entering into the universal tide of life; whether locked up with rocks, metals and beds of coal, in the bowels of the earth, or floating over its surface in the state of air and water. When once formed, the germs of plants have the power of converting the binary combinations of water and carbonic acid into ternary compositions of lignin, sugar, starch and other organic products, which are thus prepared for entering into the composition of more exalted species of organization; while it is certain, that whatever the cause of vital action may be, it is incapable of converting the elements of mineral bodies into the sap, cambium and solid structure of plants; or into chyme, chyle, blood, and the different organs of animals.

Owing to the comparative inertness of their elements, mineral bodies have the power of entering into binary combinations only, which maintain their original state of aggregation until destroyed by chemical agency, and possess no internal mechanism for renewing their composition. But the essential attribute of the elements of organized bodies is that of *mobility or activity*, by which they are kept in a state

of perpetual transformation, or transition from death to life, and from life to death.

> "All forms that perish, other forms supply,
> By turns we catch the vital breath and die."

Owing to the large amount of caloric around these elements, they are enabled to form ternary and quaternary combinations, *with the aptitude for life;* and when reduced to the condition of dead matter, they are constantly entering into binary combinations of water, carbonic acid, &c., or into the simplest forms of living organizations. But if reduced to a low temperature, all their chemical and vital affinities cease, when they assume that condition of repose which characterizes the elements of mineral bodies. The sap of plants is no longer converted into cambium, lignin, bark, leaves, flowers and fruits. The food of animals is no longer converted into chyme by uniting with gastric liquor; into chyle by uniting with bile and pancreatic juice; nor into blood during the pulmonary circulation. But when the temperature of the human body is maintained by respiration at the normal standard, it exhibits an universe of motion in miniature. Like the waters of the earth that are continually passing from the ocean by evaporation and returning to their source by rivers, the blood is conveyed with immense rapidity from the lungs and heart throughout the system, renewing its composition by the deposition of fresh organic molecules, the cohesion of which diminishes until the cause of force is expanded by action; when they are removed by absorption, conveyed into the general circulation and

thence out of the body by elimination. Not a particle remains quiescent for any considerable time, so that in about forty days, a complete revolution may be shown to be effected in its substance, if we except the cartilages, bones and teeth, which last two are almost wholly destitute of life. The cellular tissue is also endowed with a very low degree of vital energy, compared with the nervous and muscular, if we except the mucous membranes; and contains much less nitrogen in its composition.

That the power of living bodies to renew their composition by assimilation, and to reproduce their species by generation, is governed by the emphatic agency of caloric, is evident from the fact, that the power of nature to multiply organic forms is directly in proportion to the temperature of the earth, from the equator to the polar circles. It is only in the regions of perpetual summer, that the number of species, variety of structure and magnitude of form, are developed in full perfection throughout the vegetable world,—where the air is perfumed with the odours of myrrh, sandal, balm, frankincense, sugar-cane, coffee, tea, mace, cloves, nutmeg, cinnamon, pepper, tamarind, with innumerable other plants that abound with the most highly elaborated aromatics and precious drugs,—where the fig-tree, orange, lemon, date, banyan and a thousand varieties of palms, are loaded with an exuberance of delicious fruits. But as we advance to the middle latitudes, where the mean temperature is from 20° to 30° lower, we find that the more exquisitely organized vegetation of the torrid zone is, for the most part, replaced by totally different orders and genera, which

diminish in number, variety and magnitude, on to the polar circles; where only fungi, lichens, algæ, the humbler grasses and a few other plants of the most simple structure are generated during their short summer.

It is also in the tropical regions that animals have been found in the greatest number, and where they arrive at the greatest magnitude; from the ostrich, cassowary and condor of Africa and South America among birds, to the elephant, rhinoceros, hippopotamus, giraffe and camel, among mammalia, or the gigantic species of the feline tribe, as the lion, tiger, leopard, &c. But it is more especially among the cold-blooded animals, that the magnitude of the same species is found so greatly to exceed that of such as inhabit the higher latitudes. The development of the crocodile, boa, anaconda, the immense turtles of the East and West Indies, as of the enormous mollusca of the tropical seas, and the mighty forests of India, Africa and South America, is fostered by the ceaseless influence of a powerful sun.

If the whale and a few other mammalia attain to a great size in high latitudes, it is because they are supplied with an apparatus for obtaining caloric from the atmosphere by respiration, which maintains their mean temperature about 20° above that of the earth under the equator, as will be noticed further hereafter. The caloric thus acquired is preserved by means of a warm fur coat, or a subcutaneous layer of fat, that in the whale varies from eight to fifteen inches in thickness. And if there be some species of plants that remain evergreen throughout the winter, it is because they abound with oily and resinous constituents

are bad conductors, and therefore retain a sufficient amount of heat to prevent the destruction of their foliage, but not to maintain their growth.

Now whatever the cause may be by which organized bodies are enabled to renew their composition, it must determine the actions that modify their structure and functions; for the elements of which they are formed are the same in all parts of the world, with this prominent exception, that within the tropics they are continually receiving from the sun a larger proportion of that ethereal principle, (whatever men may choose to call it,) which preserves all nature in a state of activity. The elements of the air, water and crust of the earth are the same in South America as at Melville Island; which is also true of all the plants and animals that inhabit the earth. The number of species, the magnitude of their forms and complexity of organization, must therefore be regulated by the energy of the principle that causes their development, which diminishes from the hottest to the coldest parts of the globe; because in the former, the affinities of life are continually in action, but suspended for six or nine months of every year, in the middle and higher latitudes.

The experiments of Decandolle on the medicinal properties of plants, compared with their external forms and natural classification, prove that their composition depends on the vital energy by which they are developed. From which it follows, that if the phenomena that constitute their growth depend on climate, it must determine the composition of all their diversified products. If the indigenous plants and animals of the old world are different from those of the new in the same latitudes, there is a corresponding

difference of climate and season. And if the vegetation west of the Rocky Mountains be different from that of the same parallels east of that great chain, it is because the climate of the western coast of America is greatly modified and tempered by its vicinity to the Pacific Ocean, if we except the arid plains and valleys of California. Owing to the unequal distribution of land and sea, mountains, hills, plains and valleys, there is an endless diversity of climate, with a corresponding variety of organized beings.

THEORY OF RESPIRATION, AS CONNECTED WITH ANIMAL TEMPERATURE.

Nothing could afford a more striking proof that "no genuine physiological principle has ever yet been discovered," than the numerous contradictory hypotheses now prevailing in regard to the source of animal temperature; some maintaining with Black, Crawford, Lavoisier, Ellis and Dalton, that it is evolved in the lungs during respiration, by a chemical process, as in ordinary combustion; others with Bichat, that "it is a product of all the vital functions." (*Life and Death*, p. 278.) Within the last twenty years, many have embraced the theory of Sir Benjamin Brodie, who inferred from his own experiments, that animal heat is in some way generated by nervous influence, because mechanical injuries of the brain and spinal marrow were followed by a reduction of temperature. But it will be seen hereafter, that such injuries, like the influence of narcotic poisons, diminish or destroy the function of respiration; and it has been proved by the

experiments of Hastings, Holland, Flourens and many others, that the reduction of temperature may be greatly retarded by artificial inflation of the lungs after decapitation, and division of the eighth pair of nerves.

Others maintain, with Dr. Philip, that animal heat is the result of secretion; while Tiedemann contends that its evolution is "a vital act, which depends immediately on the process of nutrition, the conditional and preservative cause of life." (*Compar. Physiology*, p. 247.) Mr. Mayow says, that physiologists at present incline to the opinion that "the production of animal heat depends on nervous influence;" but without explaining how and whence the nervous system obtains it; and he adds in another page, that "the source of vital heat is unknown." (*Physiology*, pp. 79, 264.)

With Dulong and Despretz, Dr. S. Smith regards respiration as the principal source of animal temperature, but thinks there is reason to believe that the remainder is extricated from the blood by nervous influence, as in the process of secretion and nutrition. (*Philosophy of Health*, vol. ii. p. 153.) Chaussat concludes, from his own experiments, that the evolution of heat depends more on the cervical portion of the spinal marrow or medulla oblongata, than on the brain. (*Ann. de Chim. et de Phys.* tome iii.) And Müller observes, that "since all organic processes are dependent chiefly on nervous influence, it cannot appear wonderful if the reciprocal action between the organs and the nerves is a main source of animal heat." (*Elements of Physiology*, p. 86.)

As if with a view of reconciling these conflicting hypotheses, Dr. W. F. Edwards maintains, in a recent article on animal heat, contained in the *Cyclopedia of Anatomy and Physiology*, that it depends first, *on the condition of the blood; secondly, on the development of the nervous system; and thirdly, on muscular contraction;* because the temperature of animals is in proportion to the richness of their blood, and the degrees of nervous energy, muscular power, &c. At the commencement of the same article, he observes that "Physiologists have not been able to discover the cause of animal heat, for the same reason that natural philosophers have not yet discovered how heat is produced in the inorganic world." But if it be true that caloric is absolutely everywhere present, either in a combined or separate state, and cannot be traced to any more comprehensive principle, it must be allowed to possess the essential and efficient attributes of a primary cause. Moreover, I have proved that it has the power of moving itself, and of generating motion in other bodies; that if the air, the ocean and the solid ground were deprived of this active principle, they would be perfectly inert and quiescent, for the plain reason that the volume, elastic force, mobility and chemical power of all bodies are diminished by every reduction of their temperature; consequently, that caloric does not consist in the vibratory motions of ponderable matter, as supposed by Rumford, Davy, Young and others, nor in "the successive polarization of its particles;" but that it is the *cause* of vibration, without which there could be no sound, light, life nor motion in the universe. It is, therefore, chimerical

to call in question the materiality of the only agent in nature that is omnipresent, as it is to speculate about its nature or origin, unless we confine our inquiries to the mode in which it is separated from other matter, and to the mechanical, chemical and vital effects it produces.

Sir Charles Morgan observes, that "the manifest connection of living energy with temperature, and with development of the respiratory function, leads to an idea that heat is the specific bond of connection;" but that "the ignorance in which we are placed in regard to the nature and origin of fire, fixes an obvious bar to the knowledge of the affections of organized beings by that cause;" and that "the influence of respiration on life has yet to be sought;" that "in attempting to extend the limits of inquiry, the map must be traced after the discoveries of a Columbus, not covered with an imaginary Terra Australis, or fancied Atalantis," &c. (*Philosophy of Life*, pp. 148, 156, 384.) Dr. Southwood Smith also observes, that "whether the blood acquires something from the atmosphere which is essential to life, or part with something incompatible with life, is wholly unknown." (*Philosophy of Health*, vol. ii. p. 436.)

Among those physiologists who regard respiration as the source of animal temperature, it is still undecided what proportion of the oxygen consumed is converted into carbonic acid; whether the combination of oxygen with carbon takes place in the air-cells of the lungs, as maintained by Black, Crawford, Lavoisier, Ellis and Dalton; or in the general course of the circulation, as supposed by Lagrange, Hassenfratz, Ed-

wards and some others. With the exception of Priestley, the early experimenters concluded that nearly all the oxygen absorbed during respiration was expired in the form of carbonic acid. But it was soon after discovered by Crawford and Lavoisier that about 25 per cent. of the oxygen consumed disappeared; from which they concluded that it united with hydrogen to form water. Similar results were obtained by Sir H. Davy, from numerous experiments on himself; for he found that the oxygen absorbed was in the proportion of 100 to 81·66 of what was exhaled from the lungs.

It was also found by Allen and Pepys, that pigeons absorbed 16 per cent. more oxygen than they expired in the form of carbonic acid, and Guinea pigs 20 per cent. In the experiments of Berthollet, the difference was 25 and 30 per cent. in the rabbit and Guinea pig; while in those of Despretz, it was from 25 to 34 per cent. in the same species of animals. But in the cat, dog and hawk, Dulong found the difference from 20 to 50 per cent. (*Journal de Physiologie*, 1823.)

Dr. Edwards states, from his own experiments, that in Guinea pigs and yellow hammers the difference was in the ratio of 100 to 82·26; while in puppies it was as 100 to 53. He further ascertained, that green frogs and lizards consume much more oxygen than is returned in the form of carbonic acid; as Spallanzani had found to be the case in many of the lower species of animals. (*Influence of Phys. Agents on Life*, pp. 216, 218.)

What then becomes of the surplus oxygen? Does it unite with hydrogen, as supposed by Crawford, La-

voisier, Cuvier, Dulong and Despretz; or with the blood, as maintained by Edwards and many other physiologists? Müller thinks it may combine with the blood, giving it a bright arterial hue, but not with hydrogen, because Collard de Martigny found that aqueous vapour was exhaled from the lungs of animals when deprived of oxygen. But this objection is not well founded; for if 25 per cent. of the oxygen consumed by a healthy man in twenty-four hours, (which is about 45,000 cubic inches, or two pounds in round numbers,) were to unite with hydrogen, it would make only nine ounces of water; whereas it is known that from 18 to 20 ounces are exhaled from the lungs in that time. And it might just as well be denied that oxygen unites with the hydrogen of wood in the process of ordinary combustion, as that it does so during respiration.

If ever we shall be enabled to reduce the phenomena of life to the certainty of fixed principles, it must be accomplished by ascertaining the elementary composition of organized bodies, and the changes they undergo at every stage of their development; what is added to our food, during its conversion into chyme, chyle and blood; what changes are effected on the atmosphere by respiration; what the blood receives and what it loses, while passing through the lungs, and during its circulation through the systemic capillaries; above all, what enables it to excite the heart, and maintain the activity of all the vital functions. This should be the ultimate aim of our researches. For if all diseases are owing to some deviation from the natural state of organized bodies, it is clearly impossible to comprehend

the right method of their treatment, without knowing the conditions of healthy action.

Let us then agree with Aristotle, that, "if there be any description of knowledge more high and excellent than another, it is that of the animating principle." But if the cause of animal life be obtained from the atmosphere by breathing, as taught by Moses, and sanctioned by the universal common sense of mankind, it must be a *bonâ fide* constituent of the atmosphere, and not a hyperphysical essence, as supposed by some modern theorists; who have confounded the physical cause of animal motion with sensation, volition and thought, which are operations of the nervous system, and not material entities; for they cannot be added to, and subtracted from bodies, like caloric, electricity and other measurable elements.

It also follows, that if the atmosphere be composed of oxygen, nitrogen, aqueous vapour and carbonic acid, united with some still more refined essence, one of these must be the primary cause of vital action. And as it is now well known that oxygen is the only gas capable of supporting life by respiration, the question arises whether it produces the effect by its immediate agency, or by the evolution of an imponderable fluid, as during the process of combustion. But if the number, diversity and specific character of plants throughout the earth be determined by the amount of caloric derived from the sun, it follows *à fortiori* that the vital force of animals, and the development of their organization must be regulated by the quantity of the same agent, which I have shown to be the active principle in light, electricity, oxygen and all the other

forms of matter. Yet no regular and systematic attempt has ever been made to connect the theory of animal temperature with the laws of life, or the phenomena of sanguification, secretion, nutrition, sensation, volition and muscular motion.

If it can be shown that there is more carbon and hydrogen in the venous than arterial blood of all animals, they must be given off while passing through the lungs, because they are found to be diminished immediately afterwards. And if there be more nitrogen in the arterial than venous blood of animals, it must be derived from the atmosphere by respiration. But so far has this department of organic chemistry been neglected, that no one has ever attempted to ascertain the relative proportions of oxygen, carbon, hydrogen and nitrogen, in the venous and arterial blood of different animals, with the view of discovering the true theory of respiration. The consequence of thus rejecting a whole series of facts has been, that nearly everything most important to be known remains still involved in deep obscurity, or vitiated by fallacious hypotheses.

That the venous blood of all animals contains more combustible matter than that of the arteries, would appear from the following results of Michaelis, obtained by heating with oxide of copper the dry colouring matter, fibrin and albumen, separately, of blood taken from the calf. (*Schweigger's Journal*, vol. liv.) Nor can there be a doubt, that when a sufficient number of similar experiments shall have been performed on the blood of different animals, the proportions of

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carbon and hydrogen that unite with oxygen in the lungs, will be found to vary with the kinds of food.

	Colouring matter in		*Fibrin in*	
	Venous blood.	*Arterial blood.*	*Venous.*	*Arterial.*
Carbon	53·231	51·382	50·440	51·374
Nitrogen	17·392	17·253	17·207	17·587
Hydrogen	7·711	8·354	8·228	7·254
Oxygen	21·666	23·011	24·065	23·785

	Albumen in Venous blood.	*Albumen in Arterial blood.*
Carbon	52·650	53·009
Nitrogen	15·505	15·562
Hydrogen	7·359	6·993
Oxygen	24·486	24·436

Now if we take the average of the whole it will be found that the proportions are as follows:

	Venous blood.	*Arterial blood.*
Carbon	156·321	155·765
Nitrogen	50·164	50·402
Hydrogen	23·298	22·601
Oxygen	70·217	71·232

Similar results have been obtained by Mulder, who found the composition of fibrin from blood of the cow, as in the next table:

	Venous fibrin.	*Arterial fibrin.*
Carbon	53·476	53·019
Nitrogen	15·295	15·462
Hydrogen	6·952	6·828
Oxygen	24·281	24·691

So far as these analyses are to be relied on, (and they are perhaps the most correct of any yet published,) they show that the proportions of carbon and hydrogen are greater in venous than arterial blood; viz., immediately before than after passing through the

lungs; consequently, that they must be there given off. They also show that the ratios of oxygen and nitrogen are greater in arterial than venous blood. That a portion of nitrogen is absorbed from the atmosphere and united chemically with the blood, might reasonably be inferred from the fact, that there is much less of it in the food of herbivorous than in that of carnivorous animals; as will be seen when I come to treat of aliments.

Now if it be true that animals consume from 20 to 50 per cent. more oxygen by respiration than is returned in the form of carbonic acid, as shown by the experiments of Dulong, Despretz, Edwards and Treviranus, what, I repeat, becomes of the surplus oxygen? Does it unite with the hydrogen exhaled from the lungs; or with the blood, as supposed by Edwards and others? That it combines with hydrogen to form water, and contributes largely to the evolution of animal heat, is evident from the fact, that there is no other mode of accounting for the disappearance of the surplus oxygen or of the hydrogen given off by venous blood in the lungs. Nor has it ever been proved that the combination of oxygen with the blood is attended with an elevation of temperature, unless carbonic acid or water be formed. Edwards maintains that carbonic acid is formed in the general course of the circulation, because he found it to be exhaled in notable quantities from the lungs of frogs and young kittens, when confined in vessels of pure hydrogen, and from fishes placed in water deprived of oxygen. Müller also states, as the result of his own experiments and those of Bergman, that frogs exhale from three-tenths

to ninety-six hundredths cubic inch of carbonic acid in from six to twelve hours, in gases that contain no oxygen; or nearly as much as they generate in atmospheric air. (*Elements of Physiology*, p. 339.)

The objection to these experiments is, that they prove too much, since it is manifestly impossible that an animal can exist for any considerable time without oxygen, except in a torpid state. That small proportions of carbonic acid may be exhaled by cold-blooded animals while confined in an atmosphere of hydrogen or nitrogen, is evident from the fact, that at the ordinary temperature of the atmosphere, water absorbs its own volume of carbonic acid. So that as animals are composed of 80 per cent. of water, it is not very surprising that when deprived of oxygen, frogs should exhale an amount of carbonic acid nearly equal in volume to that of their whole bodies, in the space of from six to twelve hours.

But it is impossible to reconcile the results of Edwards, Müller and Bergman with the experiments of Mr. Ellis, who found that carbon (not carbonic acid) was exhaled from the stigmata of bees and other insects, after all the oxygen of the air in which they were confined was consumed. (*Inquiries*, sections 133, 137 and 671.) The formation of carbonic acid in the blood is also disproved by the fact, that variable proportions of carbon and hydrogen are given off by venous blood while passing through the lungs, as shown by their diminished quantity in arterial blood, according to the analyses of Michaelis, already given.

That different gases may exist in a state of mechanical mixture with the blood, and be separated from it

by means of the air-pump, has been shown by the experiments of Magnus, who found the proportions of carbonic acid, oxygen and nitrogen, in the arterial and venous blood of the horse and calf, as follows; making from 10 to 12½ per cent. of gaseous matter by volume.

	HORSE.		CALF.	
	Arterial.	*Venous.*	*Arterial.*	*Venous.*
Carbonic acid	17·7	18·8	16·4	16·3
Oxygen	6·3	4·8	6·5	2·8
Nitrogen	2·5	2·8	4·2	1·9

These experiments show that there is more oxygen and nitrogen in arterial than in venous blood, and a little more carbonic acid in the latter. But if they prove anything in regard to the theory of respiration, it is, that carbonic acid is not formed in the general circulation. For if generated in the arterial blood, it ought to contain more carbon than venous blood, which is not the case; and if in venous blood, its temperature ought to be higher than that of the arteries; for the obvious reason, that caloric is always evolved during the formation of carbonic acid. But the most decisive proof that the latter is generated in the lungs, and not in the general circulation, is, that *the temperature of arterial is higher than that of venous blood*, as long ago observed by Haller, Black, Plenck and Menzies.

This important fact, which was denied by Cullen, and overlooked by nearly all other physiologists, has been completely established by the experiments of Dr. John Davy, Magendie and Holland. In an excellent paper, recorded in the *Philosophical Transactions* for 1814, it was shown by Davy, that in lambs, sheep and

oxen, the blood is from 1° to 1·5° warmer in the carotid arteries and left ventricle of the heart than in the jugular veins and right ventricle.

In another series of observations made in 1838, and recently published among other physiological researches, he has shown, that in sheep, the difference is in some cases 3°. In one case, he found the temperature of the right pleura 107°, while that of the jugular vein was 106°. In another the lung was 108°, and the rectum 105°. In a third sheep, the lung was 109°, and the rectum 106°, the air being at 51° F. He also found that the blood of a spaniel bitch was 104° in the right side of the heart, but 107° in the left ventricle and pleura; thus demonstrating that the lungs have a higher temperature than other parts of the body, which Cullen had ironically said ought to be the case, if animal heat were the effect of respiration.* And as Haycraft, De la Rive and Marcet had shown that equal volumes of the different gases have the same capacity for heat, Davy proved that it is nearly the same in arterial and venous blood; thus sweeping away all the crude speculations founded on the erroneous experiments of Crawford, who represented the capacity of oxygen gas as 4·7, compared with carbonic acid, which he made 1·6; that of arterial blood as 1·03, and venous blood as ·89. Yet Dr. Davy

* It has been absurdly enough maintained, that if the whole of the caloric were disengaged in the lungs, their temperature would be so great as to consume them in a short time. Were it not known that all the blood, together with the heat which it obtains in the lungs, is distributed throughout the body every three minutes, there would be some reason for this objection.

maintains that animal heat is owing to the fixation or condensation of oxygen in the blood, and to the combinations into which it enters in the circulation. (*Physiological and Anat. Researches*, vol. ii. pp. 171, 212 and 214.)

Müller observes, that the formation of carbonic acid in the capillary vessels of the body explains why the lungs are not warmer than any other part of the system. (*Elements*, p. 333.) But we have seen from the reliable observations of Davy, that the pleura, surrounding the lungs, and the blood that comes immediately from them, are actually warmer than other parts of the body. And as the fact has been called in question by other physiologists, I repeated his experiments on sheep and oxen several times during the winters of 1839–40, and 1840–41; the result of which was, that in every trial, the temperature of the lungs and left side of the heart was from 2° to 3° higher than that of the stomach, liver and brain, or the blood of the *vena cava* and jugular veins.*

Müller adds, that the object of respiration is evidently the absorption of oxygen into the blood, which conveys that gas as a stimulus to the different organs

* The animal was first knocked down, and the vessels of the neck divided. The thorax was then opened, and a small aperture made with a penknife, into the right ventricle of the heart, into which the bulb of a delicate thermometer was introduced, after being put in warm water, near the temperature of the animal. In two or three minutes, the same process was performed on the left ventricle, and the difference of temperature noted. Could the experiment be performed on animals without first arresting respiration, it is probable that the difference between the temperature of arterial and venous blood, in large animals, would be still greater.

of the body; and secondly, the removal from the blood of the carbonic acid which is formed in the capillaries. (*Elements*, vol. ii. p. 341.) But that oxygen does not excite the heart to contract, the stomach to digest, the nerves to feel, the brain to think, and the various organs to perform their respective functions, would appear from the experiments of Bichat, who found that when injected into the jugular veins of a dog, death speedily ensued; and it is known that farriers are in the habit of killing horses no longer fit for service, by injecting air into the veins. Nysten also found that when oxygen was introduced into the venous blood of animals, no carbonic acid was evolved, although it acquired the scarlet hue of arterial blood. And that atmospheric oxygen is not essential to the existence of those imperfect organizations termed entozoa, which are formed in the brain, liver, muscles, eyes and other parts of the higher animals, is evident from the fact, that it has no access to them, which is also true in regard to the primordial germs of all animals.*

* A decisive proof that the blood of animals is not vitalized by oxidation and decarbonization, is, that during the respiration of plants, carbonic acid is absorbed by the leaves and decomposed, its carbon being retained, and its oxygen returned to the atmosphere, the purity of which is thus maintained. Dr. Gilly found that when grass leaves were exposed to the sun in a jar four hours, the following changes were produced:

At the beginning of the experiment, there was in the jar:—		At the close of the experiment, there was in the jar:—	
of Nitrogen	10·507	of Nitrogen	10·507
Carbonic acid	5·700	Carbonic acid	·37
Oxygen	2·793	Oxygen	7·790
	19·000		18·667

That a small proportion of oxygen is absorbed by the blood, and contributes to its formation, is highly probable; but I have proved that by far the greater part of it unites immediately with carbon and hydrogen in the lungs. If then it be true, that caloric is always disengaged during the formation of carbonic acid and water, and that the lungs are the source of animal temperature, the latter cannot be "owing to the fixation or condensation of oxygen in the blood, and the combinations into which it enters in the circulation," as maintained by Dr. Davy; nor to "the combination of oxygen with carbon in the systemic capillaries," as supposed by many modern physiologists.

Should it still be urged, that the agitation of venous blood with oxygen gives it the arterial colour, I answer that sugar, nitrate of potassa, sulphate of soda, chloride of sodium, carbonate of potassa, sal ammoniac and even carburetted hydrogen, (according to Berzelius,) produce the same effect, but destroy its vitality and power of coagulating. Moreover, when arterial blood is withdrawn from the system, it acquires the colour and other properties of venous blood, without either the loss or gain of ponderable matter. For it was found by Hunter, that on tying the carotid artery of a dog in two places, the blood between the ligatures soon acquired the dark venous hue; and by Hassen-

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But that the circulation of sap, and its conversion into the nutritive fluid of plants, is effected by the agency of solar heat, is evident from the fact, that neither light, electricity, air, water nor any other physical agent, will produce these phenomena at a low temperature.

fratz, that when confined in glass tubes, hermetically sealed, it underwent the same change of colour as when placed *in vacuo*, hydrogen, nitrogen, carbonic acid or common air. Müller admits, that as arterial is converted into venous blood while passing through the systemic capillaries, the former ought to contain principally oxygen, and the latter carbonic acid in solution. But we have seen, from the experiments of Magnus which he reports, that arterial contains nearly the same proportion of carbonic acid as venous blood, but the former a little more oxygen and nitrogen. The truth is, that if carbonic acid were formed in the systemic capillaries, (as maintained by Edwards, Müller, Prout and others,) they ought to have a higher temperature than the lungs, for the obvious reason, that wherever oxygen unites with carbon, caloric is evolved, whether during ordinary combustion, fermentation or respiration. But that the temperature of arterial blood is reduced, instead of being augmented in the systemic capillaries, is evident from the fact, that on returning to the right side of the heart, it is found to have lost from 1° to 3° of caloric, together with its bright florid hue, and power of maintaining the actions of life, just as the steam of an engine loses its elastic force and the power of moving the piston, after undergoing a reduction of temperature.

That venous is converted into arterial blood during its passage through the lungs, was long ago proved by the experiments of Lower, Mayow,* Hewson, Hunter,

* The nitro acrid spirit of Mayow was oxygen, which he calls "spiritus vitalis igneus." (Part I, of *Tractus de Sal. Nitro et Spiritu Nitro Acrio, and Aër Purus Vitalis*, p. 281.)

Goodwin and Bichat, who, in various species of animals, observed it to pass from the right side of the heart, through the pulmonary artery, of a dark hue, and return by the pulmonary veins to the left ventricle, of a bright florid complexion. It must not, however, be supposed that the vital properties of the blood are essentially connected with its colour, which is absent in insects, in nearly all the lower orders of invertebrated animals, and is confined to a small proportion of the blood in fishes; from which it would appear, that colour is rather a concomitant, than an essential or vital property of the blood.*

In regard to the agency of caloric in producing a change of colour, some interesting experiments were performed by Crawford, who found that after immersing a dog, with the exception of his head, in water at 45° F. for fifteen minutes, his venous blood was the darkest he had ever observed; but on placing another dog in water at 114° for thirty minutes, it was of a scarlet hue, and could scarcely be distinguished from that of a neighbouring artery.† (*Experiments and Ob-*

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* It has been recently maintained by Dr. G. O. Rees, that the particles of venous blood contain phosphorus, which also unites with atmospheric oxygen, to form phosphoric acid, which again unites with the alkali of the liquor sanguinis, and forms a tribasic phosphate of soda, that produces the florid hue of arterial blood, like other salts.

† He supposed that the dark colour of venous blood was owing to the carbon it obtained during its circulation through the systemic capillaries; and that by elevating the temperature of an animal above the natural standard, this change was prevented from taking place. But the experiments of Hunter, Hassenfratz and others, demonstrate that arterial blood passes into the venous state

servations on Animal Heat, pp. 310, 387.) And Dr. John Davy states, that there is much less difference between the colour of arterial and venous blood of sheep when the temperature is 80° or 90°, than during winter in England, or when the mercury is below 32°. (*Physiological and Anatomical Researches*, vol. ii. p. 140.) In accordance with these facts, it may be observed, that after immersion for some time in a cold bath, the surface of the body assumes a purple hue, as when exposed to a very cold atmosphere; but if transferred to a warm bath, the skin changes to a bright scarlet colour. The reason of this difference is, that the cold bath prevents the blood of the cutaneous vessels from passing freely through the lungs, where it is arterialized; whereas the warm bath augments the circulation in all parts of the body.

Again, if it were established that venous blood is brightened by uniting with oxygen, and darkened by the presence of carbonic acid, the injection of oxygen into the veins will not support life when the chemical function of the lungs is arrested, any more than nitrogen, hydrogen or any other description of ponderable matter. As a further proof that oxygen is not the agent by which the fluids are formed, and converted into the various tissues by vital affinity, it has no access to the germ of the fœtus, which is nourished and

without either the loss of oxygen or the gain of carbon. Magnus also found, that by depriving venous blood of its carbonic acid, it is not changed to the scarlet hue of arterial blood. Moreover, if the serum be removed from a clot of venous blood, and the latter be washed with distilled water, oxygen no longer imparts to it the arterial colour, as when it is immersed in serum.

lives before any communication is established with the blood of the mother by means of the placenta.

From all the foregoing facts we are authorized to conclude, 1. That during the passage of dark venous blood through the lungs, it gives off variable proportions of carbon and hydrogen, that unite chemically with atmospheric oxygen to form carbonic acid and water, as in ordinary combustion, by which it acquires an addition of caloric, with a bright florid hue; and 2. That during its circulation through the systemic capillaries, the caloric obtained from the atmosphere is transferred to the solids, by which their temperature and vitality are maintained, when the blood returns to the right side of the heart of a dark modena hue, having lost its power of stimulating the organs, until it acquires an additional quantity of caloric from the lungs.

Dr. Prout observes, in his late *Bridgewater Treatise*, that "the phenomena of life are wholly removed from the logic of quantity." But if respiration be the source of animal life, the phenomena are resolvable into additions and subtractions of measurable elements; and it is only because they have not been ascertained with numerical accuracy, that physiology has never yet been reduced to the character of an exact science. For if it be true that the conversion of food into chyme and chyle is effected by its union with gastric juice, bile and pancreatic liquor; that chyle is transformed into more highly organized particles of blood, by giving off water, carbon and hydrogen, while passing through the lungs, in exchange for which it receives caloric from the atmosphere, with variable pro-

portions of nitrogen, there is no good reason why the proportions of each should not be reduced to "the logic of quantity."

According to some recent experiments of Dr. Ure, caloric enough is evolved during the combustion of one pound of charcoal to melt 75 pounds of ice, which would raise 150 pounds of water 70°. Now if we suppose that 45,000 cubic inches of oxygen are consumed by a healthy man in 24 hours, making about two pounds in round numbers; and that 40,000 cubic inches, or a little more than one pound twelve ounces are expired in the form of carbonic acid, it must unite with about 12 ounces of carbon:* so that if the same proportion of caloric be given out as in ordinary combustion, it ought to compensate the loss of 52½° in a man weighing 150 pounds. And if the remaining 5000 cubic inches of oxygen combine with one-eighth its weight of hydrogen, (the proportion of oxygen which disappears is generally much larger in carnivorous animals,) it ought to raise the temperature of 150 pounds of water 12°; allowing, with Dr. Thomson, that caloric enough is evolved during the combustion of one pound of hydrogen to melt 400 pounds of ice.

The supposition of Dulong and Despretz, that more caloric is given off by animals than can be accounted

* Dr. Dalton calculated that the aliment which he took in 24 hours contained about 11½ ounces of carbon; but that the mean quantity exhaled from the lungs did not exceed 10¼ ounces, the remainder passing off with the other excretions. He thinks that of the six pounds of food and drink taken daily by a healthy man, one pound consists of carbon and nitrogen, the remainder being chiefly water. (*Manchester Memoirs*, vol. ii. new series; and *Ed. New Phil. Journal*, 1832, 1833.)

for by the amount of oxygen absorbed, has been refuted by Liebig, who very justly observes, that while surrounded by water at 47·5°, as in the experiments of Despretz, the temperature of the water was raised at the expense of the animals, which were proportionally cooled; and that even if the windpipe had been tied, there would have been a rise of temperature in the water without any combustion of oxygen. Dumas also observes, that it is the cooling of the animal, not taken into the account by Dulong and Despretz, which expresses the excess of heat that has been attributed by them and other physiologists to a peculiar power in the system, independent of respiration.

In regard to the hypothesis of M. Despretz, that "the small remaining portion" of caloric not accounted for by respiration, is generated by motion of the blood, friction, assimilation, &c., I answer, that whenever the process of respiration is arrested, the motion of the blood, friction, assimilation, &c. are no longer carried on, and that the temperature of the whole system falls rapidly to that of the surrounding medium.

In reply to the arguments of Brodie, Philip, Tiedemann, Edwards and others, who contend that animal heat is generated by nervous influence, secretion, nutrition, the condition of the blood and muscular contraction, I shall proceed to prove that *the mean healthy temperature of all animals is directly in proportion to the amount of their respiration;* without which there could be no sanguification, secretion, nutrition, nervous influence nor muscular contraction, and that they have mistaken effects for the cause of animal heat.

CHAPTER III.

INFLUENCE OF RESPIRATION ON THE TEMPERATURE AND VITAL ENERGY OF ANIMALS.

"If errors had not been rooted in men's first notions, some things justly discovered might have rectified others; but as errors have been fundamental, and of such a kind that men have rather neglected and passed things over, than formed a wrong or false judgment about them, it is no wonder if they never attained what they never had in view; not arrived at the end they never proposed; nor performed the course which they never entered."—BACON.

If ever medicine be destined to take its appropriate rank among the exact sciences, it must be founded on precise and enlarged views of the cause which governs all the movements of nature, including those of the animal economy. And there is abundant reason to hope, that when mankind shall be once thoroughly aroused to the importance of throwing off the paralyzing trammels of authority, they will very soon be able to dispel the numerous obscurities that have hitherto retarded the progress of science. For it is certain that if the cause of sanguification, digestion, secretion, nutrition, sensation and muscular motion be derived from the air by breathing, *it must be a positive agent, subject to the logic of quantity*, whatever men may say about its mysterious and hyperphysical properties.

Having already shown that the power of the earth

to multiply organic forms is regulated by the amount of caloric it receives from the solar fountain, I proceed to prove that *the organizing power of animals, and the activity of their respective functions, are directly in proportion to the quantity of the same active principle derived from the atmosphere by respiration.*

Among all the operations of nature, there is nothing more calculated to excite admiration than the silent, beautiful process of living combustion; for it is so immediately connected with that by which blood is formed, that both may be regarded as one and the same act. Every time chyle passes through the lungs, it gives off carbon and hydrogen, that unite with atmospheric oxygen, by which heat is evolved, and blood generated. We have also seen that venous blood is constantly renovated by giving off what is superfluous, and by receiving from the atmosphere what is essential; in short, that respiration, sanguification and calorification, constitute but one process. It has been known since the time of Linnæus and Dr. Black, that all the higher orders of animals are warm-blooded; that they have a double heart and a double circulation, by one of which their blood is distributed throughout the lungs, where it is exposed to the atmosphere; and by the other, sent throughout the system, —that the breathing apparatus of birds is larger, in proportion to the size of their bodies, than in any other description of animals, extending through all the cavities of the abdomen, and even of the bones; that they consume more oxygen, generate more carbonic acid, and have a higher mean temperature.

Next to birds, mammiferous animals have the largest

organs of respiration. And although confined to the thorax, they consist of innumerable cells that present a vast extent of surface to the atmosphere. The consequence of which is, that many of them are capable of maintaining their temperature in the coldest parts of the world. Accordingly, it will be seen by glancing over the following tables, that the mean temperature of birds varies from 105° to nearly 113° F. which is about 28° above that of the tropical regions; while in mammalia it varies from 96° to 106° in their active and healthy state. But if we descend to the lower orders of air-breathing vertebrated animals, such as chelonians, saurians, ophidians and batrachians, in which the heart is so constructed that only a portion of blood is sent through their imperfectly developed lungs, we find that the power of obtaining caloric from the air by respiration is small; that their temperature rises and falls with that of the surrounding medium, and rarely exceeds it more than a few degrees in their most active condition; while in fishes, crustacea, mollusca, annelida and all the more imperfect animals that live in water, and breathe by means of branchiæ or gills, it is still less, as may be seen by referring to the third table.

It was discovered by Lavoisier, more than fifty years ago, that two sparrows confined in a vessel of air, generated more carbonic acid in a given time than a young Guinea pig under the same circumstances. And it has been recently estimated by Treviranus, from the experiments of different physiologists, that for every 100 grains weight of birds, they generate in 100 minutes nearly twice as much carbonic acid as mammalia, and the latter above eight times more than the frog,

as may be observed in the ensuing table. (*Müller's Elements*, p. 312.)

	Oxygen consumed. Cubic inch English.	Carbonic acid exhaled. Cubic inch.	
Pigeon	1·14	0·96	Allen and Pepys.
"	1·58	0·99	Despretz.
Guinea Pig	0·67	0·42	Berthollet.
"	0·74	0·60	Allen and Pepys.
"	0·68	0·47	Despretz.
Rabbit	0·60	0·44	Berthollet.
Cat	0·98	0·66	Despretz.
Frog	0·00	0·06	Müller and Treviranus.

TABLE I.

TEMPERATURE OF BIRDS.

Names of the animals.	Temperature of the animals.	Observers.
Bearded Vulture	112·89° F.	Pallas.
Snow Bunting	110·24	"
Grouse	108·	"
Snipe (Lesser Godwit)	108·	"
Oyster Catcher	106·	"
Bullfinch	108·	"
Ruff	108·	"
Redpole	111·70	"
Female	110·24	"
Swallow	111·70	"
Hawk	109·72	"
Pigeon	106° to 112·75	Holland.
The same	109·37	Despretz.
Sparrow	Feb. 105°...Apr. 108° to 111· July.	Edwards.
A young Drake	111·	Dr. J. Davy.
" Duck	110·	"
Adult Turkey Cock	109·	"
Turkey Hen	108·	"
Fowl, full grown	108·50	"
two months old	111·	"
Goose	107° to 111·	"
Guinea Hen	110·	"
Common Thrush	109·	"
Jackdaw	107·75	"
Screech Owl	106·	"
Common Crow	108·15	Despretz.
Yellow-hammer	109·18	"
Mean of the whole	109·53	

Nearly all the foregoing results were obtained by introducing the thermometer into the rectum, during life, or into the blood or entrails soon after death. It is also worthy of notice, that the temperature of vigorous young birds is somewhat higher than that of adults, as in the duck, and common fowl; and higher in the male than female, as in the turkey, duck and redpole. The experiments of Dr. Edwards on the sparrow, in connection with those of Dr. J. Davy on the human subject, would further lead to the conclusion, that the temperature of all the smaller species of animals is higher during summer than winter.

TABLE II.

TEMPERATURE OF MAMMALIA.

Names of the animals.	Temperature of the animals.	Observers.
Man	96° to 102° F.*	Davy.
Monkey (Sim. Aygulia)	101 to 104·50	"
Sheep	103 to 106·	"
Spaniel Bitch	105·	"
Cur Dog	102·50 to 103·50	"
Bull Dog	102·	"
Jackal	101·	"
Common Cat	101 to 102·	"
The same	103·60	Despretz.
Leopard	102·	Davy.
Goat	103 to 104·	"
Elk	103·	"
Guinea Pig	102·	"
Common Hog	103·	"
The same	104·	Braun.
Calf	104·	"
Hare	104·	Pallas.
Rabbit	103·5 to 106·50	Holland.

* From the observations of Dr. John Davy on one hundred and fourteen individuals of the human species, of both sexes and of all ages, in various parts of the world between England and the tropical portions of the East Indies, the temperature in the month varied from 96·5° to 102°, and was generally found to be 1° or [illegible] r when and where the atmosphere was at 80°, than in England [illegible] er seasons of the year.

TABLE II.—(CONTINUED.)

Names of the animals.	Temperature of the animals.	Observers.
Arctic Fox	106·75*	Fisher.
The same (the air,—32°)	106·	"
Female (the air, 26°)	104·75	"
Wolf (the air, 27°)	105·	"
Ermine	104·45	Pallas.
Squirrel	102·	Davy.
Common Rat	102·	"
Weasel	103·	"
Horse	99·50	"
Indian Elephant	99·50	"
Ox	100 to 101·	"
The Whale	102·	Scoresby.
Porpoise	100·	"
Polar Bear	100·	Capt. Lyon.
Tiger (Ceylon)	98·	Davy.

TABLE III.

TEMPERATURE OF COLD-BLOODED ANIMALS.

Names of the animals.	Temp. of the medium.	Temp. of the animals.	Observers.
Large tropical Turtle	79·50° F.	84·00°	Davy.
The same	80·	88·50	"
Common Frog	61·	70·	"
Active Lizard	74·75	82·61	Czermack.
Green "	61·25	68·50	"
Spotted "	54·	59·	"
Chameleon	72·	74·	Murray.
Coluber	83·	90·	Davy.
A brown Snake	82·50	84·50	"
Adders	58·	68·	Hunter.
Boa	73·	75·	Wilford.
Natrix Lævis	69·	80·	Czermack.
Proteus Anguinus	59·55	68 73	"
Geometrical Tortoise	61·	86·90	Davy.
Another	79·	91·	"
Shark ... in water	74·75	77·	"
Bonito (Tunny)	80·50	82·	"

* In fifteen out of sixteen foxes, the temperature was from 100° to 106·75°, in the other 98°. (*Parry's Journal of a Voyage*, &c., p. 157.)

TABLE III.—(Continued.)

Names of the animals.	Temp. of the medium.	Temp. of the animals.	Observers.
Common Trout	56·	58·	Davy.
Flying Fish	75·50	78·	"
Crab	51·80	59·	Rudolphi.
Black Snails	54·	57·	"
Earth Worms ... in a vial	56·	58·89	J. Hunter.
Leeches ... "	54·	56·80	"
Bees in the hive ... in May		102·	Réaumer. (Nat. Hist. des Insects.)
The same ... in Jan	6·	55·	Réaumer. (Nat. Hist. des Insects.)
Swarming season		104·	Huber. (Mem. sur les Abeilles.)
In winter	30·	86·	Huber. (Mem. sur les Abeilles.)
An Ant-hill	55·40	68·	

After the foregoing sheets were printed, being obliged to retire into the country for a few months, in consequence of ill-health, brought on by over-exertion of the nervous system, from too intense application to the subject of this work—I embraced the opportunity of making some additional observations on the temperature of such domestic animals as came in my way. Most of them were made in the month of August, by placing the bulb of a medical thermometer under the forearm, which was gently pressed against the thorax. They were performed with a view of ascertaining the influence of season and of age in modifying temperature. From which it will be seen, that in some of the more active mammalia, it was higher than the average represented in the second table. The observations on fowls, ducks and a few other birds, cor-

responded with those of Davy and Edwards, therefore have been omitted as unnecessary.

TABLE IV.

Temperature of a young she-goat, three months old	107°
Mother of the same, old, and in poor condition	104
A tame young rabbit, two months old	108
A fine active kitten, two months old	105·5
A vigorous cat, nearly full-grown	104
Mother of the kitten, three years old	103·5
A very old cat, said to be in its nineteenth year	102
An active cur dog, three months old	106
A fine active young horse, four years old	104
A mare, twenty years of age, (in vaginam)	100

Thus it would appear, that in the same species of animals, the temperature is higher during youth than middle age, still lower in old age, and higher during summer than at any other season. We have seen that Dr. J. Davy found it higher in the human species under the tongue, within the tropical than the temperate latitudes. And I have ascertained by about one hundred observations on myself, during the last eighteen months, that a nicely graduated thermometer placed under the tongue, varies from 97° to 100° during winter, and from 100° to 102° or 103° occasionally, during summer; while in April and May, the average has been about 100°.* I have also found it from 1° to 2° higher on first awaking in the morning, and throughout the day, than at twelve o'clock at night, when it has always been at the minimum, except

* On the 18th of May, 1846, the temperature of the air was above 80° at New York, when that under my tongue and *in currente urinæ* was 101°, but the next morning at eight o'clock, the temperature of the air, after a north wind and thunder-storm, had fallen to 53°, and that under the tongue was 99°.

after taking supper, or returning from a brisk walk, both of which augment the quantity of respiration.

But what is the specific office of caloric in the operations of life? Within the last few years I have often propounded this question to various members of the medical profession, without receiving any better answer, than that *it is to keep us warm.* With a view of ascertaining what the uneducated portion of the community think about it, the question was put to a London barber:—*What is the use of animal heat?* To which he replied, without hesitation, "*to make us live and grow!*" Surprised at the novelty of this answer, his reasons were demanded, when he again replied, with equal readiness, "*Without the heat of the sun there could be no life and growth of plants.*" Such is the difference between the unsophisticated common sense of mankind, founded on the daily observation of what is continually passing around us in nature, and the mystic jargon of books filled with metaphysical speculations about "the unknown vital principle"—speculations which have tended only to divert the votaries of science from the path that leads to the acquisition of positive and useful knowledge.

> "Some truth there is, but dash'd and brew'd with lies,
> To please the fools, and puzzle all the wise."—DRYDEN.

Corresponding with the facts exhibited in the foregoing tables, the whole organization of birds is more highly developed, and their different functions are performed with greater rapidity than in mammalia. The stomach is more concentrated, digestion more vigorous, the heart larger in proportion to their weight, its walls thicker, its pulsations stronger and more frequent.

Their blood is more highly organized, or richer in fibrin and red particles, their secretions more copious, and the renewal of their composition by nutrition more rapid. Their bones are harder, their muscles more firm, and their vital power of contraction greater, as shown by the activity of all their movements, and the immense velocity with which many of them glide through the pathless air to distant regions, in opposition to the force of gravity. For it is well known that the hawk and eagle are capable of flying forty-five miles per hour, the carrier-pigeon from fifty to sixty, and a species of swallow termed the swift, at the rate of ninety miles per hour,—which, if continued for twelve hours, would make 1080 miles a day. And such is the enormous strength of the ostrich, combined with rapidity of movement, that, if we are to credit the account of Adanson, as reported by Mason Good, it has been known, with a negro on its back equal to double its own weight, which is about eighty pounds, to outrun the swiftest race-horse. (*Book of Nature*, vol. i. 325.)

So great is the power of digestion in birds, that common fowls require two and a half ounces of solid barley per day, as proved by the experiments of Moubray; or about one-twentieth of their whole weight, supposing the latter to average three pounds. But there is reason to believe, that the smaller and more active species of birds consume a much larger proportion of oxygen than fowls, geese, turkeys, ducks and other large birds, especially such as are confined to the surface of the earth. For if it be true, as stated by Lavoisier, that two sparrows generate and expire more carbonic acid in a given time than a young

Guinea pig, they must consume three times the ratio of oxygen; as the average weight of sparrows is about one ounce, and that of a young Guinea pig about six ounces, while it is worthy of notice, that they are both graminivorous animals. In accordance with these data, which can be regarded only as approximations to the truth, Moubray says, that the domestic pigeon requires one ounce two drachms of solid barley per day; so that if we estimate the average weight of pigeons at twelve ounces, they must digest about one-tenth of their whole weight every twenty-four hours. It therefore follows that, as barley consists of 86·8 per cent. of solid nutritive matter, and the living body of about twenty per cent., the rest being water, the composition of fowls is renewed in a period not much exceeding ten days, and that of pigeons in a much shorter time, as might be inferred from the rapidity of their growth, which is remarkable in all the feathered tribes.

The brain and nervous system are also more highly developed in small than in the larger species of birds;* especially in the canary, bullfinch and several other songsters, as in the parrot tribe, and more so in some

* On the authority of Haller and Cuvier, Mr. Lawrence gives the weight of the brain in several species of birds, compared with that of the whole body, as follows:—

Canary	1 : 14	Blackbird	1 : 68
Sparrow	1 : 25	Falcon	1 : 102
Chaffinch	1 : 27	Duck	1 : 257
Fringilla	1 : 27	Eagle	1 : 260
Red-breast	1 : 32	Goose	1 : 360

Nor is it unworthy of notice, that in the ostrich, cassowary, swan, condor and turkey the relative size of the brain is still less, corresponding with their well-known stupidity.

of them than in any other description of animals, not even excepting man. Hence the remarkable acuteness of their senses, their sagacity in foreseeing changes of weather, in the construction of their nests, and in providing for their wants. Hence, also, their delightful genius for music, the social and almost human affections of some, including the faculty of articulating words, together with all those beautiful instincts which many have justly regarded as a species of inspiration. But although in a very few of them the brain is larger in proportion to the size of the body than in man, its convolutions are less numerous, and its frontal portions less developed, coinciding with the activity, yet limited range of their intelligence. Nor is it unworthy of passing notice, that the pigeon, sparrow, and some other among the smaller species of the feathered tribes, rear from six to eight broods of young every season, in the middle latitudes, all of which attain their growth in a few weeks; while the common fowl often affords one hundred eggs annually, if well-nourished and protected from the inclemency of the weather, or even one hundred and fifty, in a few cases, according to Buffon.

Again, those mammalia in which the organs of respiration are most fully developed, possess the highest degrees of vital energy. For example, the chest of the dog, wolf, fox, goat, deer, horse, ox, sheep, hare, rabbit and some other species of quadrupeds is larger, in proportion to the size of the body, than that of man, and their temperature several degrees higher, as we have already seen. The consequence of which is, that they are capable of resisting much greater degrees of

cold, and of enduring muscular exertion for a much longer time, without exhaustion.* The thorax of the greyhound is larger, in proportion to his size, than that of any other quadruped; and it is well known that, for a short distance, he will surpass the swiftest race-horse,—that, with a fair field, he will overtake the hare, fox, deer and rabbit in a few minutes, during which his speed is equal to that of the wild-pigeon, which flies at the rate of a mile every minute for several hours.

The thorax of the common foxhound is larger, in proportion to his weight, than that of the ordinary horse, and he will pursue the chase for a longer time without exhaustion—sometimes for above three hours,

* When I come to treat on the influence of climate and season, food and drink, exercise, repose, &c. it will be shown that the lungs of man and other mammalia, from the greater necessity of exercising them, are more developed in the higher latitudes than in the tropical regions,—that they are larger in the dog, wolf, fox, polar bear, reindeer and other animals which inhabit cold climates, in proportion to the size of the body, than in the elephant, rhinoceros, camel, tiger, leopard, or even the lion,—whose temperature, muscular activity and power of enduring cold are proportionally less. It will also be seen that respiration, the power of enduring intense cold and protracted muscular exertion, are greatly diminished by starvation, and that vital heat is expended by over-exertion faster than acquired. As an example of this, it has been said that 30,000 horses belonging to the French army perished in one week, chiefly from cold, during the fatal retreat from Moscow, when the mercury was only 4° F. below 0°; whereas it is certain that, when well fed and not over-exerted, this noble animal is capable of enduring a temperature of 36°, and even 40° below 0° F., without house or clothing.

and to the distance of forty or fifty miles.* As a further proof that the vital energy of the hound exceeds that of the horse, the former requires one and a half pounds of actual nourishment per day, such as hard biscuit and fat, making one-fortieth of his whole weight, which is about sixty pounds. But the usual allowance of a common work-horse is equivalent to twelve quarts of oats per day; so that if a bushel of oats average thirty-seven pounds,† two-thirds of which, or twenty-four and a half pounds, consist of pure meal, he must consume above nine pounds of solid food, independent of chaff; and about one-seventieth of his whole weight, if the latter be estimated at seven hundred pounds. From which it follows, that the composition of the

* Captain Lyon, when in the arctic regions, had an Esquimaux dog, which dragged one hundred and sixty pounds at the rate of six and two-third miles an hour for seven or eight hours a day. Such dogs will draw a heavy sledge to a considerable distance, at the rate of thirteen or fourteen miles an hour; and they will travel long journeys at half that rate, each of them pulling the weight of one hundred and thirty pounds.

The strength of the elephant is reckoned equal to that of six horses; but he consumes a greater ratio of food, and will carry a load of three or four thousand pounds.

† A bushel of oats weighs from thirty-two to forty-two pounds, (average thirty-seven pounds,) and affords 74·3 per cent. of actual nourishment, according to the analysis of Sir H. Davy. The cavalry allowance in England is four feeds, consisting of eight quarts of oats every twenty-four hours, and twelve pounds of good meadow hay, which contains about twenty-five per cent. of nutritive matter,—making in all nine pounds of nourishment. In Spain and Portugal, horses in the army are allowed eight pounds of barley per day.

hound is renewed in about ten days, and that of the horse in about twenty days.

The capacity of the chest and nostrils of the fine-blooded race-horse is also larger, in proportion to the size of his body, than in any other description of the horse-kind; corresponding with his great muscular strength and activity. These conditions are owing to the expansion of his lungs, and the development of the muscular system by active exercise, by which he is disencumbered of all useless fat; so that the greater part of his blood and vital energy are expended on the organs of locomotion.* Besides, we are informed by Darvill, that, while in training, he requires fifteen quarts of oats daily, which must afford about twelve

* For the same reason, the goat, sheep, deer, ox, hog, ass and many other animals, are more active in the wild state than when domesticated, over-nourished and prevented from taking much exercise. The wild buffalo, or bison, is no less remarkable for the size of his chest than for strength and swiftness in running, compared with the tame and unwieldy ox. The wild ass, also, is scarcely surpassed in fleetness by the finest horse, although slow in his general movements when made a mere beast of burden. But even then his muscular strength is superior to that of man; for a small donkey, not exceeding the weight of a large man, will carry two hundred and twenty pounds a distance of twenty miles a day, which is certainly more than the stoutest porter could perform. We are, therefore, authorized to conclude, that all animals whose power of obtaining caloric from the atmosphere by respiration exceeds that of man, surpass him in the powers of digestion, secretion, nutrition and muscular motion. The reproductive power of the rabbit, hare, cat, dog, hog and other animals of hot temperament, is also greater than in man,—greater in nearly all the different species of birds and mammalia, especially those of small size, during summer than winter, when they are also less playful and sprightly.

pounds of actual nourishment. It is, therefore, obvious, that a larger amount of carbon and hydrogen is given off by the lungs of the race-horse than by those of the ordinary horse, *cæteris paribus*,—that he obtains more caloric from the atmosphere by respiration; that his blood is richer and more abundant; and that his composition is renewed more rapidly, or in about seventeen days.

Again, that the aggregate vital energy of the horse is greater, in proportion to his size, than that of man, would appear from the following facts:—First, that his tractive power has been found equal to that of six men, whose collective weight is about six times 150 pounds, making in all 900 pounds; whereas that of the horse has been estimated at an average of only 700 pounds: Secondly, that a man in full health, weighing 150 pounds, digests about one and a half pounds of actual nourishment daily, which is only about one one-hundredth of his whole weight, and much less than what we have seen to be the ratio consumed by the horse. From which it follows, that, in a state of the most vigorous health, man requires only twenty-five days for the renewal of his organization, allowing that all his actual nourishment is converted into blood and his several tissues, before it is discharged from the body in the form of excretions. But it remains to be ascertained what proportion of the food is consumed in the lungs by combustion, during the conversion of chyle into blood. When this question is settled, it will probably be found that the composition of man is renewed in from 30 to 40 days, instead of seven years, but that of birds and the more

active mammalia in much shorter periods. Coinciding with the above facts, it is well known to medical men, that a broken bone of a healthy individual, when rightly set, acquires its former strength in about forty days, more or less, according to the age and constitution of the patient.*

The thorax is larger in men than in women, its mean circumference being about thirty-six inches in the former, and thirty-two in the latter. It is therefore not surprising that the blood of men is more highly organized, their muscles more fully developed, their brains from four to eight ounces larger, (as shown by Tiedemann,) with a corresponding superiority of muscular and intellectual power. *Nor was there ever an individual of great vital energy, whether of the brain, stomach or muscles, without large and sound lungs, which are essential to the sanguine and heroic temperament.*

If we descend to the lower orders of air-breathing animals, whose mean healthy temperature is from 30° to 50° below that of birds† and mammalia, and

* But so rapid is the nutritive or formative process in birds, that, when a bone is broken, it requires only about three weeks to unite and become strong, if kept in apposition. The *Vis medicatrix Naturæ* is, therefore, only another name for the aggregate vital energy of animals, and is in proportion to the quantity of caloric they derive from the atmosphere by respiration.

† That birds consume at least twenty times more oxygen, in proportion to their weight, than reptiles, would appear from some experiments performed by Dr. Edwards, who found that a frog was capable of living above three days when confined in a vessel containing sixty-four cubic inches of common air; (with a solution of pure potassa for absorbing the carbonic acid exhaled,) whereas, un-

falls to that of the surrounding medium during winter in the higher latitudes, we shall find that their powers of digestion, circulation, sanguification, secretion, nutrition and muscular motion, are exceedingly low,—that the lungs, heart, stomach, brain, muscles and other organs, are imperfectly developed, compared with the whale, dolphin, porpoise and other cetacea, which have large lungs, abundance of rich arterial blood, and, like all warm-blooded animals, an highly organized stomach, heart, brain and muscular system. The truth is, that *scarcely any part of reptiles is more than half formed; while some of their organs may be said to exist in a merely rudimentary state.* Corresponding with the obtuseness of their senses, and the low grade of their intelligence, it has been observed by naturalists, that the brain of a crocodile twelve feet

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der the same circumstances, a yellow-hammer of the same weight lived only one hour. Nor can there be a doubt that many of the smaller birds devour more food in one day than reptiles of the same size in twenty. For it is well known, that frogs, toads, salamanders, tortoises and many other reptiles, are capable of living several weeks without food, or suffering any material diminution of weight, and that serpents are often many weeks in digesting a single meal. Spallanzani relates an instance of one that was three months in completing the digestion of a fowl. He also found that in snakes, the process was more rapid in June, when the temperature was 82°, than in April when at 60°. Hence the slow growth of all cold-blooded animals, compared with birds and mammalia. Nor can there be a doubt that the muscular power of the latter is from ten to twenty times greater than that of reptiles, *cæteris paribus*,—for example, that in a horse weighing 700 pounds it is ten times greater than in a tropical turtle of the same weight, and twenty times greater in a sparrow than a frog.

long, and of a serpent eighteen feet long, does not exceed from one to two ounces in weight.

If we descend the scale of organization from reptiles to fishes, crustacea, mollusca and other animals which breathe with gills instead of lungs, and live constantly in water, which contains only about one per cent. of free oxygen by volume, we find, that although formed of the same elements, animated by the same principle, and constructed after the same model, as the highest species, *they resemble abortions, compared with the finished beauty of form exhibited in birds and mammalia.* For example, the heart of fishes is exceedingly small, its walls thin, its pulsations slow and languid, the arteries small and few, the blood pale and watery, the muscles flaccid, the bones soft or replaced by cartilage, while the brain consists of a few small knots or ganglions, with a corresponding defect of the senses.* And notwithstanding they move with great velocity through water, it is owing to the density of that medium, by which they are enabled to propel themselves onward by a small exertion of vital force; nearly all of which is expended on the muscles employed in locomotion. But as Cuvier observes, they are soon exhausted by exertion, which is true of all cold-blooded animals.

As a further proof that *the aggregate vital energy of all animals is directly in proportion to the development*

* The eyes are without lustre, the organs of hearing scarcely distinguishable, and so imperfect are those of voice, that they have no power of uttering sounds, but vegetate in perpetual dumb silence, with scarcely the animal desire of sexual communion, or the slightest regard for their offspring.

of their breathing apparatus, it may be added, that by means of stigmata or holes, arranged along their bodies, and minute vesicles for conveying air throughout the system, the active insects are more fully supplied with organs of respiration than any other description of animals, not excepting birds. As an example of the large amount of oxygen they consume, Spallanzani found that a caterpillar generated more carbonic acid in a given time than a frog, and butterflies still more. Corresponding also with the facts exhibited in Table III. p. 513, we learn from the experiments of Mr. Newport, recorded in the *Phil. Transactions* for 1836–7, that wasps, hornets, beetles, moths and some other insects, have a much higher temperature than that of the surrounding air, and that it is always in proportion to the quantity of oxygen they consume by respiration, which is augmented by exertion, and diminished by repose.

In accordance with the above facts, and with all the analogies of nature, the whole organization of the higher insects is very complex and refined. For, although like all invertebrated animals, they have no brain in the head, nor central sensorium, they are supplied with a series of knots or ganglions, extending along the interior of their bodies, and connected with each other by nervous cords; while it is known that some of them are covered over with eyes. Hence the extreme acuteness of their senses, and the wonderful sagacity displayed in the economy of bees, ants and many other species of insects. The honey-bee has, to a certain extent, the same emotions of fear, anger, revenge and affection, as man. It also remembers, compares

and reasons; for, while disporting in the joyous sunshine, and culling sweets from the flowery fields, it looks forward to a change of season, avoids the approach of rain, wind and other injurious conditions of the weather; while in the construction of its honey-cells it exhibits the perfection of mathematical skill.

We are told that all this is mere *instinct*, because it is not improved by education. But if we admit that bees construct their cells with as much art the first day of their commencing to labour, as after three years of experience, and that they do it by *instinct*, must not the latter depend on the peculiar organization of their nervous system? And if within the limited range of their appointed labours, they operate with more consummate skill, without education and experience, than man, it is because they are employed on only a few objects, to which they are adapted by their organization, and directed by a species of physical necessity, arising from their wants; just as birds of passage are directed by their sensations to seek warmer climates on the approach of winter,—or for the same reason that the eye of the eagle can discover small objects at a great distance, and that the sense of smell is more acute in the common hound, than in any other description of animals, viz., because the optic and olfactory nerves are larger, and expanded over a greater extent of surface. Descartes gave the true theory of instinct, when he said that "the lower animals do many things better than ourselves,—not because they are endowed with more reason, but that nature acts in them according to the structure of their organs." (*De Methodo.*)

As an example of the complex mechanism of the higher insects, we are informed that Lyonet discovered 4061 distinct muscles in the *Cossus*, while in the caterpillar state. And as an example of the prodigious muscular power of the more perfect insects, Richerand states, that the common grasshopper has been known to leap two hundred times its own length; while there is reason to believe, that in proportion to his size, the flea is still more active and strong. The muscular power of insects is still more remarkably shown by the fact that a small number of bees while suspended from the limb of a tree will support for some time a swarm of several thousand, whose aggregate weight is equal to from three to six pounds.

CHAPTER IV.

A FURTHER INQUIRY INTO THE PHYSICAL CAUSE OF VITAL ACTION.

"In physiology, what a vast advance would that philosopher make who should establish a precise, tenable and consistent conception of life."—WHEWELL.

As in every department of human knowledge one radical error leads to others in endless sequence, it is not surprising that erroneous views in regard to the cause of vital action should have involved the whole science of medicine in a maze of perplexity and uncertainty. The fatal consequences of ignorance in regard to what the living principle is, and how it operates, may be traced in the unsettled opinions which everywhere prevail concerning the essence of fever, its causes and its treatment, a state of things that calls loudly for reform *ab origine*.

In all attempts to improve the science of physiology, it should be our leading object to discover the primary physical cause of animal motion; and whether it resides in the blood, as maintained by Moses, Hippocrates and all the ancients; or in the nervous system, as supposed by the great majority of modern authors. Until these fundamental questions are decided, the theory of life, health and disease, must continue involved in profound darkness. Nor is it less certain,

that the whole theory of nature must remain a sealed book, so long as attraction, repulsion, chemical affinity, polarity, irritability and sensibility, are regarded as ultimate phenomena, or confounded with primary causation. It is therefore high time that we should look beyond the surface of things to the mainspring of all power, whether in living or dead matter.

In accordance with the universal belief of antiquity, it was maintained by the illustrious Harvey, that what the Romans termed *calor vitalis*, is *the primary and immediate cause of the heart's action, and of vitality in the blood, which he describes as the common bond of union among all parts of the living body.* "In quo, vegetativæ et sensitivæ operationes primo elucent, cui calor, primarium et immediatum animæ instrumentum, innascitur, qui corporis animæque commune vinculum est,—et quo vehiculo anima omnibus totius corporis partibus influit." (*Op. Omnia*, p. 388.) He further maintained that the animating principle is a finite portion of the universal spirit that actuates all creation.

But this simple and rational doctrine was destined to be superseded by the speculations of Willis, Baglivi, Hoffman, Gaubius and Barthez, who confounded the animating principle with some unknown hypothetical fluid, supposed to be generated in the brain, from which it was conveyed to all parts of the body by nerves. According to Stahl, the organizing principle which he termed the *Anima*, is endowed with intelligence, and corresponds to the Φυσις of Hippocrates, with this exception, that Stahl regarded it as an immaterial essence.

It was also maintained by the celebrated Boerhaave that all the operations of the living body are governed by the agency of an universal catholic fluid, the most subtile and elastic principle in nature, termed by the Greeks and Romans *Anima Mundi.* But he supposed that the action of the heart, stomach and other involuntary organs is owing partly to the influence of arterial blood, and partly to the agency of a *nervous fluid*, generated in the cerebellum; while the voluntary muscles derive their power from the influence of a nervous fluid secreted in the cerebrum, as first suggested by Willis. And so confused were his notions in regard to the source of animal heat, that with Bacon, Boyle, Borelli and other mechanical physiologists, he represents it as an *effect of the heart's action, friction and motion of the blood, because when the circulation is vigorous, the body is warm, but cold when it is languid.** (*Institutions in Physic*, pp. 16, 61 and 116.)

Although it must be confessed that this logic is not precisely after the manner of Euclid, it is not a bad specimen of what may be found in the works of many distinguished modern philosophers, who have equally confounded cause and effect. Sir Isaac Newton himself has fallen into a like error, when he says that "*animal motion may be performed by vibrations of the ether, excited in the brain by the power of the will.*" But

* He further maintained, like Hoffman, that every variety of fever and inflammation is owing to a deranged condition of the blood, and its too slow or too rapid movements, as during the cold and hot stages; that all spasmodic affections are owing to a vigorous influx of nervous influence into the muscles, and paralysis, to a stoppage of that influx. (*Op. cit.* pp. 216, 250.)

how can the brain will, unless previously vitalized? And if the will depend on the activity of the brain, how can it be the cause of vibrations in the ether, or of any species of cerebral motion? Is it not manifest, that sensation, memory and volition are mere modes of action of the living nervous system? For, when life ceases, they are wholly extinguished, therefore, like the mind itself, cannot be regarded as material entities, (as they have neither extension, solidity, nor any other properties of tangible matter,) but as effects of the same cause that generates attraction, repulsion, vibration, chemical affinity and all the motions of passive matter.

But it was reserved for the celebrated Cullen to erect on the ruins of nearly all that was true in the medical doctrines of antiquity, one of the most visionary systems ever invented by the subtilizing genius of man; and which has exerted an astonishing influence in retarding the progress of sound practical knowledge. Although he admits that all the phenomena of health and disease must be referred to the moving powers of the animal economy, he maintains that digestion, circulation, secretion, nutrition, sensation and muscular motion, including the generation of animal heat, are owing to the agency of a "*subtile and elastic principle*,*

* But if caloric, in some of its forms, be the cause of all elasticity, it must be the very same principle which Cullen terms the nervous fluid, and describes as the prime mover in the animal economy. Yet, so little did he know in regard to the origin and use of animal heat, that, in his *Institutions of Medicine*, he speaks of it "as probably the effect of the motion of the blood, because in dying animals the heat grows less as the motion of the blood grows

inherent in the medullary substance of the brain; and which he termed the nervous fluid, or the nervous power, —that this fluid or power is the prime mover in the animal body, and determines the activity of all the organs, whether voluntary or involuntary,—that as it appears only in the living, and disappears entirely in the dead state of the body, it must be regarded as the vital principle,"—and that it regulates not only the various degrees of muscular strength, but the quantity, quality and distribution of the fluids, with every variety of temperament. (*Materia Medica*, pp. 55, 88 and 99.)

In accordance with this hypothesis, he taught that all medicinal and morbific agents exert their influence primarily on the nervous system, and not through the medium of the blood, as maintained from the days of Hippocrates down to the time of Harvey. And it is remarkable that he should have rejected the humoral pathology, on the ground of our ignorance in regard to the office of blood in health, and of the changes it undergoes in disease.

The supposition that nervous influence is indispensable to muscular contraction, was long ago disproved by the experiments of Haller and Fontana, who found, that when the chest of an animal was laid open, and the nerves going to the heart were stimulated, its contractions were neither accelerated nor renewed when at rest. And Dr. Philip has since demonstrated, that even the voluntary muscles retain their irritability as

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less; and when at death it ceases altogether, the heat ceases also in a very short time." That such a sentence should have been written by Cullen after he had been made acquainted with the discoveries of Dr. Black, is almost incredible.

long after their nerves have been divided as when left entire,—that chemical stimulants which excite them to contract when applied immediately to their fibres, produce no effect when applied to their nerves alone.* Yet the majority of modern physiologists who have not adopted the views of Cullen, maintain with Haller, that all the phenomena of animal life may be referred to two fundamental properties, *irritability* and *sensibility*, the one inherent in the muscular fibre, and the other in the medullary tissue. But as these properties cannot exist in any part of the body before it is

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* He says, that "the power of the muscular fibre is a property depending on the mechanism of that fibre, and in no degree directly depending on the nervous power." Yet he maintains that "animal heat must be ranked among the secretions:" that it is evolved from the blood like the various secretions, by nervous influence, because the temperature of animals is reduced by injuries of the brain, spinal marrow and division of the vagus or eighth pair of nerves, and their secretions diminished; as if the cause of muscular contraction were different from that of secretion. In another place he observes, "we have reason to believe that nervous influence is the galvanic fluid, collected by the brain and spinal marrow, and sent along the nerves." But he says again, that "neither nervous influence nor galvanism can excite the actions of animal life, except in parts endowed with the vital principle, whether the latter be something superadded to bodies, or only a peculiar arrangement of their parts." (*Experimental Enquiry*, pp. 156, 219, 248, 265, 267, &c.)

It is painful to trace the flounderings and contradictions of so great an experimenter as Dr. Philip, who has overlooked the admirable precept of Newton, that no more causes of natural things ought to be admitted, than such as are true and sufficient to explain the phenomena. For if neither galvanic electricity nor nervous influence can excite the actions of life in parts not endowed with the vital principle, why admit them as causes of secretion and the evolution of animal heat?

formed, it is self-evident that they are secondary effects of the organizing principle; while it is equally manifest, that the *vital attraction*, the *vital affinity* and the *vital contractility* of Dr. Alison are modifications of one and the same power by which the blood is formed, united with the different organs, and the whole maintained in a state of activity.

The theory of Bichat was only a modification of that proposed by Cullen; for he referred the contractile power of the heart and all the involuntary organs to the ganglionic system of nerves, which he regarded as the source of organic or unconscious life,—(corresponding with that of plants, the *vital* and *natural functions* of the ancients, and those termed *vegetative* by Harvey;) while he supposed that the brain, spinal marrow and their nerves were the organs of sensation, perception and the power of regulating the movements of the voluntary muscles. The objections to this theory are—1. That contractility is a property of all living matter, including every description of plants, and even the medullary tissue; for the brain undergoes contraction and expansion during violent emotions or active thinking. 2. That all the operations of life, whether voluntary or involuntary, are *organic*. 3. That among all the lower orders of animals which have neither brain nor spinal marrow, but only ganglionic nerves, and some of them only a single cord extending along the body, as in the earth-worm, there is not a single species destitute of sensibility, consciousness and volition; for the lowest worm seeks nourishment, and recoils from the approach of harm: while the more active insects are endowed with far higher degrees of intelli-

gence than many animals which have a brain and spinal marrow,—with emotions of love, anger, fear, and perhaps, to a certain extent, the sentiments of justice and benevolence.

Thus it is, that without resorting to the cruel experiments of vivisection, (which always deranges the natural state of the functions, and has led to so many erroneous conclusions,) we learn by a simple appeal to comparative physiology, that the office of the ganglionic nerves is identical with that of the brain, spinal marrow and their nerves. For, as Cuvier truly observes, by comparing the structure and functions of different species, in which "nature adds to, or subtracts from, each of their different parts, just as we might wish to do in our laboratories, and shows herself the results of such additions and subtractions," we may easily ascertain the specific office of any one organ. We may obtain responses from nature by putting her to the torture; but, like the prisoner when submitted to the rack, her answers are often fallacious. The truth is, that the brain may be regarded as a large ganglion, or concentration of nervous matter, of which the spinal marrow is a mere continuation; and the nerves of both, as expanded branches, with which the ganglions in the higher animals are connected; and the object of which is to endow the involuntary organs with so much sensibility as may be requisite to their well-being. But as the heart, stomach and all secretory organs are excited to action by the stimulus of blood, there is no necessity for their being subject to the commands of the *sensorium commune,* like the locomotive muscles, or even the sphincters of the bladder

and rectum. Let us, then, reject the doctrine of Müller, that "the ganglia are the centres of organic life;" and that "the cerebro-spinal system alone is capable of exciting voluntary motion." (*Elements of Physiology*, pp. 734, 934.)

The celebrated Cuvier seems at one time to have aimed at more enlarged views of the animal economy; for he observes that the vital energy of animals, and the development of their organization, are in proportion to the amount of their respiration. But, like his illustrious predecessor, John Hunter, he was so completely fettered by the prevailing doctrine of the schools, that in his introduction to the *Regne Animal*, he says that, "as the heart, stomach and other involuntary organs are affected by the nervous system, it is probably the source of their contractile power." And again: "as all the animal fluids are derived from the blood by secretion, there cannot be a doubt that the *nervous fluid* is secreted by the medullary matter, from which it is conveyed to all parts of the body by the nerves."

The fundamental error of regarding the brain, or any part of the nervous system, as the source of vital energy, will appear evident from the following undeniable facts:—1. That life exists throughout the vegetable world, and in many species of the lower animals termed zoophytes, polypi, entozoa, &c. in which not the slightest trace of nervous matter has ever been discovered; consequently, that all those physiologists who have regarded nervous influence as the source of vital energy, have vainly endeavoured to explain an universal by a partial fact. 2. That the germs of all

the higher animals are developed and endowed with vitality, before any part of the nervous system is formed; consequently, that the latter must be a secondary effect or product of the organizing principle. 3. That the aggregate vital energy of animals is directly in proportion to the quantity of their respiration, or of caloric that passes through their tissues, and bears no uniform relation to the development of the brain and nerves. 4. That the nervous system, like all the other organs, is formed from, and vitalized by, the blood, which is formed in the lungs by the same active principle that causes the seeds of plants to germinate, and the germs of animals to unfold from a simple albuminous mass into highly organized bodies.

Yet we are told by Tiedemann, "that the development of the locomotive organs is in proportion to that of the nervous system." (*Compar. Physiology*, p. 182.) And Mr. Mayow says, that "the nervous system determines the rate at which each function proceeds, the quantity of secretion and the frequency of involuntary motion." (*Outlines of Physiology*, p. 264.) Again, Magendi observes, that "we are totally ignorant in regard to the cause of muscular motion, but must seek for the impulse which sets our various tissues in motion, in the nervous system." (*Lectures on the Nerv. System*.) Dr. Edwards also maintains, that "the predominance of the nervous system in warm-blooded animals renders all parts of the body more excitable, giving the greatest energy to the nutritive functions." And Sir Charles Bell observes, in his late work on the *Nervous System*, that "vital power is possessed through the agency of nervous matter, diffused through all ani-

mals, from the simplest up to man." (1836, p. 17.) Dr. Billing also maintains, that "the nervous system regulates and supplies all the organs with energy, and that without nerves there is no organic contractility." (*Principles of Medicine.*) And Müller contends, that "the organs of animals manifest as great a dependence on nerves, as plants do on light." (*Op. citat*, p. 43.) In the same strain, we are told by Mr. Earle, that "the agent which causes animal heat, the fluidity of the blood, and maintains all the functions of life, is something which proceeds from the brain, along the spinal marrow to the extremities of the nerves; and that animal heat is as much to be considered a secretion as bile, saliva or gastric juice." (*New Expos. of the Nerv. System*, p. 137.)

As if to fill up the measure of our astonishment, Edward Johnson observes, that the heart and all the other organs derive their power of action from a fluid brought to them by the nerves from the brain, by whose action that fluid is produced,—that wherever there is an artery, vein or absorbent, there must also be a nerve to enable these vessels to convey their fluids, &c. But, as if conscious that all this amounts to nothing in the way of explanation, he says again: "If you ask me for the cause of the first life, I answer your question by another:—What is the cause of gravitation, chemical affinity, &c. but the *Causa Causarum?* the *Deity himself?*" (*Life, Health and Disease*, pp. 66–72.)

But why should I quote further examples of a doctrine which is taught by nearly all modern physiologists, and by some of them carried even farther than

was ever contemplated by Cullen? Having already shown that nervous influence is not the cause, but a secondary effect of vital energy, it may be right to show, by a brief reference to comparative physiology, that the muscular strength and locomotive power of animals are not in any proportion to the development of the nervous system. As a striking example of this, the brain of man is perhaps fifty times larger than that of the ostrich, which is no less remarkable for stupidity, than for its prodigious muscular power; for, if we are to credit the accounts of travellers in Africa, it has been known to surpass, with a full-grown negro on its back, the fleetest race-horse.* She does not, however, seem to be ignorant of the fact, that her eggs may be hatched by the agency of solar heat, independent of nervous influence, when buried in the hot sands of Senegal, where she sits on them only at night.†

The brain of the greyhound, like that of the fox, hare, rabbit, goat, deer and many other species of

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* It is said of the ostrich in the Book of Job, chap. xxxix. verse 17, that "God hath deprived her of wisdom, neither hath he imparted to her understanding."

† A similar view has been *recently* advanced by Dr. Draper of New York; for he says that "the beams of the sun are the true nervous principle in plants;" that to the yellow ray is assigned their nutritive processes, to the blue their movements. But unfortunately for this latter hypothesis, if kept in air of the proper temperature, all the movements of plants, including the decomposition of carbonic acid by their leaves, their circulation and nutrition are carried on in the midst of profound darkness, if we except the process by which their colours are produced. (See *Phil. Mag.* for August, 1844, p. 104.)

mammalia, is exceedingly small: but as he is made up chiefly of lungs, blood and muscles, he is the swiftest of all runners except the ostrich. The brain of the horse and ox varies in weight from one pound four ounces to one pound seven ounces; while that of man varies from three pounds two ounces to four pounds six ounces. Yet the muscular power of the horse is equal to that of six men. Besides, if the brain were the source of vital energy, such men as Bacon, Shakspeare, Newton, Milton, Franklin, Napoleon, Byron and all others that have large heads, ought to possess the energies of life in the highest degree; whereas it is certain, that, in men of genius, the powers of digestion, secretion, nutrition and muscular motion, are generally inferior to what they are in individuals of the athletic temperament, who are often remarkable for the smallness of their heads, and a deficiency of intelligence.

According to Rudolphi, the brain of a full-grown Greenland whale, (*Balena Mysticetus,*) seventy-five feet long, weighs only five pounds ten ounces four drachms. But as the cetacea have large lungs, and a temperature that varies from 100° to 104°, with a corresponding amount of rich red blood, the muscular power of the whale is equal to that of several hundred men. John Hunter states, that, from the capacity of the heart and aorta, from 80 to 120 pounds of blood must be discharged by the left ventricle at each contraction. The weight of this enormous animal has been estimated at 140,000 pounds; and it has been said that, when of the largest size, it has afforded above 20,000 pounds of oil. We have no accurate information in

regard to the weight of the brain in the sperm whale, which measures eighty-four feet in length, and is larger than the *Balena Mysticetus.* But Mr. Beale states, that the cranial cavity of one, fifty-eight feet six inches long, measured fourteen inches in width, ten inches in length, and nine inches in depth; that the spinal canal, which is of a triangular form, measured ten inches in width at the base, where connected with the brain, and eight inches in depth; but only seven inches wide, and six and a half deep, at the seventh dorsal vertebra, from which it diminished to the termination.*

Should it be urged that the brain of the elephant weighs from eight to ten pounds, I answer, that his muscular power is far inferior to that of the horse, ox, dog, wolf, deer and other mammalia, in proportion to their size. So that, notwithstanding the absolute size of the brain is larger in the whale and elephant than in man, it is very much smaller, compared with the

* The most remarkable fact connected with the natural history of the cetacea is, the length of time they are capable of remaining under water. Mr. Beale says, that the male sperm whale continues below the surface from one hour to seventy, and even eighty minutes, when he rises and breathes for ten minutes; but that the female remains only twenty minutes below and four minutes above the surface. (*Beale on the Sperm Whale*, p. 45.) The means by which they are enabled to effect this, exhibit a striking adaptation to the medium in which they exist, and doubtless depend on the vast amount of blood contained in the numerous convolutions of vessels found in the thoracic and abdominal cavities, as first noticed by Hunter,—all of which is vitalized during the short time they remain above water, by a rapid process of breathing, and thus prepared to maintain the activity of their functions from twenty to sixty, and even eighty minutes, while in search of food in the depths of the ocean.

magnitude of the body, and its superior frontal portions less perfectly developed. The consequence of which is, that, in the range of their intellectual faculties, they are as far inferior to man as they are his superiors in muscular power. And although the brain of the canary, sparrow and chaffinch, be larger, in proportion to the size of the body, than in any other animated beings with which we are acquainted, its convolutions are much less numerous than in man, and the intellectual portions less fully developed, compared with the inferior and posterior compartments. But the muscular power of these birds is not greater, in proportion to their weight, than that of the pigeon, whose brain, compared with the whole body, is in the ratio of one to ninety; while in man the average ratio is as one to forty), excepting idiots, in which it is often not much larger than in infants, according to the measurements of Tiedemann,) but varies with the different degrees of obesity, and diminishes with old age. We are, therefore, authorized to conclude, that *the intelligence of animals is directly in proportion to the development of their nervous system*, cæteris paribus; *but that their powers of digestion, circulation, secretion, nutrition, absorption, muscular motion and cerebration, depend on the amount of caloric they derive from the atmosphere by respiration.**

The specific office of the brain, spinal marrow and

* So far is it from being true that the brain is the source of vital energy to the other organs, that when snakes, eels and other cold-blooded animals are decapitated, the trunk remains alive much longer than the head. And Whytt states, that Redi extracted the brain from a tortoise, which afterwards lived from November until

their nerves, including those of the ganglionic system, is to endow animals with sensation, perception, memory, volition, instinct and all the attributes of mind, —to *direct* the various movements of the body, but not to supply the moving power,—to generate ideas, but not organic products. It is very true, that the nervous system is far more highly developed in warm than in cold-blooded animals; but we shall see presently, that this is owing to the greater activity of nutrition in the former. It is also very true, that when the nerves going to a voluntary muscle are irritated,

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the following May, but lost the power of vision and hearing. (*Essay on Animal Motion*, p. 386.)

It is also evident, from the experiments of Flourens, that in the highest orders of animals, the cerebrum is not essential to respiration, which is governed chiefly by the eighth pair of nerves, that arise from the medulla oblongata. For he found that, when the cerebrum of a chicken was removed, it remained in a healthy state for ten months, and even grew fat on being daily crammed with food,—that, when thrown into the air, it exerted its wings, as if endeavouring to fly, but lost the power of vision, hearing, tasting, smelling, the feeling of hunger, sexual desire, memory, comparison, and, to a great extent, all its sentient faculties. Yet we are informed by Magendie, that after the cerebrum, cerebellum and all parts of the brain above the medulla oblongata, were removed from a hedgehog, the animal retained, in a low degree, the sense of feeling, smelling and consciousness,—uttered cries when its whiskers were plucked, and made repeated efforts with its forefeet to get rid of the annoyance. Volkman also found, that, when a decapitated frog was irritated with a hot iron, it leaped forward, as if conscious of pain. We further learn, from the experiments of Granger and Barron, that, after the brain was removed from a young puppy, it made efforts to suck,—thus showing an imperfect power of volition. (*Med. Gazette*, April 13, 1839.)

contractions are produced, and that, when divided, it can no longer contract in obedience to the commands of the will. But if the locomotive organs be not supplied with arterial blood, they become cold, insensible and paralytic, whatever the condition of the brain may be. And if the blood be not supplied continually with caloric by respiration, it cannot excite the brain to think and will, the nerves to feel, the muscles to contract and the glands to secrete.*

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* In his late *History of the Inductive Sciences*, Mr. Whewell observes, that "the phenomena of the nervous system bring us in a striking manner to the passage from the physical to the hyperphysical sciences;" and he adds, that "the *nervous fluid* can neither be mechanical, chemical nor physical,—that it must cease to be a fluid before its motions can become sensation and thought." (Vol. iii. pp. 422–430.) But if the nervous fluid be neither mechanical, chemical nor physical, it must be a non-entity, or a metaphysical phantom, and should therefore be excluded from the inductive sciences. "What can we reason but from what we know?" Yet Mr. Earle has described the circulation of the nervous fluid with as much confidence as did Harvey that of the blood. Dr. Alison also maintains, that "vitality has no connection whatever with the notion of mind as distinguished from matter." And even Lord Brougham has so far forgotten himself as to hazard the assertion, that "mind has no necessary connection with sensation." But it might as well be said, that motion has no connection whatever with matter, as that mind has no necessary connection with the vitality of the nervous system, or with sensation; for it is self-evident that, in our present state of existence, there can be no perception, memory, comparison or νοῦς, without sensation, and no sensation without life; consequently, that all the phenomena of mind are strictly physiological. And it is only when we attempt to speculate about the operations of the soul, independent of matter and of all corporeal organization, that we lose ourselves in the labyrinth of the hyperphysical sciences, among what Lord Bacon

It has often been asked, what is the use of nerves in parts not subject to the will? I answer, that without nerves in the stomach, we could not be informed by the sense of hunger, when and how much nourishment to take; that without nerves, the heart, liver, bowels and other viscera, could not warn us of approaching disease by the sensation of pain, nor direct in the employment of suitable remedies. Through the agency of nerves distributed to the respiratory muscles, we are enabled to regulate the process of breathing, and thus to obtain the principle of life from the atmosphere. To this act, the infant is first prompted by the painful sensation of a pressing vital want, which forces the little being to utter a cry, when the lungs expand for the reception of air, and all his embryo faculties are exalted. This half unconscious feeling continues to operate throughout the remainder of existence, and when all the outward senses are steeped in oblivion; for "not even in sleep is will resigned," as proved by the fact that respiration still goes on, though somewhat diminished, while all the higher functions of the brain are suspended. Hence it is, that when the *vagus* or eighth pair of nerves is divided, the process of breathing is diminished, the temperature of the body reduced, sanguification, secretion, nutrition, &c. impaired,—or even wholly suspended by destruction of the brain and spinal marrow—simply because respiration is a voluntary process, and the *primary function of life*, on which all the

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calls "*the idols of the Den.*" The genesis of all mental phenomena must be sought in our organization, and that of organization in the union of spirit and matter.

others depend. Division of the nerves going to the stomach, pancreas, kidneys and other glands, does not prevent them from secreting their respective fluids; but if cut off from the supply of living blood by dividing or tying their arteries, the powers of secretion, nutrition, sensation and motion, are wholly suspended.

The sensorium may be compared to the commander of an army, whose office it is to direct its movements; but the moving power resides in the army and not in the general. The external senses may also be compared to the sentinels which give information of what is going on, while the nerves operate as messengers that convey orders from the chief to the ranks, and bring back information in regard to their condition. So long as the commander fulfils his duty, the evolutions of the army are performed with order and intelligence; but should he be slain or wounded, and his place not be taken by another chief,—or should his means of communication with his subordinate officers be cut off, the operations of the army become irregular, confused and inefficient, because no longer guided by superior intelligence. In like manner, when the sentient power of the brain has been destroyed by suffocation, strangulation or a violent concussion, the locomotive muscles contract spasmodically, because no longer directed by the organ of thought.

So far is the brain from being the source of moving power in the animal economy, that arterial blood is more essential to its vitality than to any of the other organs; for if the carotid and vertebral arteries be divided or tied, it dies almost immediately,—and long before the heart and other muscles cease to contract.

The reason of which is, that the brain is supplied with five or six times more blood in proportion to its magnitude, than the general system—corresponding with its exalted vitality, and the important office it has to perform as the organ of mind, by which we are enabled to hold communion with the external world, and to enjoy whatever is beautiful or excellent in the universe. For the same reason, birds die much sooner after decapitation or the privation of oxygen, than mammalia, and the latter than cold-blooded animals. In other words, it is because arterial blood is more essential to the vitality of the brain than to any of the other organs, that it dies in a few moments when deprived of that fluid, or when the latter is no longer arterialized by respiration;* whereas the contractile

* For example, when the smaller birds are deprived of oxygen, or the vessels that supply the brain with blood are divided, they become insensible in 40 seconds. When insects are smeared over with varnish, so as to prevent respiration, they die almost immediately, as shown by the experiments of Treviranus; the more active mammalia in about one minute,—whereas in man, sensibility remains for about one minute and a half, after the process of breathing has been arrested by exposure to mephitic gases, strangulation from hanging or drowning, as found by the experiments of Goodwyn and Bichat. But when reptiles and fishes are deprived of oxygen, or the great vessels are divided, they often maintain a low degree of vitality for several hours, and even for several days when the energy of their functions has been diminished by external cold. We also learn from the researches of Legallois and Edwards, that puppies, kittens and other mammalia that are born with the eyes closed, (and in which the function of respiration is so imperfect as to resemble that of cold-blooded animals,) may be resuscitated after remaining above half an hour under water. The rationale of which is, that in proportion to the vital energy of animals, is the rapidity

power of the muscles remains for a long time, and is not wholly extinguished until the body becomes cold, as shown by the rigidity or stiffening that takes place after death.

This brings us to one of the most important laws of the animal economy, which, when fully understood, will unfold the rationale of spasmodic diseases, and lead to the true method of curing, or rather of preventing them—viz., that *the duration of life in any part of the body, when deprived of arterial blood, or the animating principle, is inversely as the quantity of blood required to maintain its activity.* The consequence of this law is, that whenever the chemical function of the lungs is diminished, and the vital properties of the blood are impaired, the voluntary power of the brain ceases to operate some time before the moving power of the muscles, which contract without its orders, and therefore in a convulsive manner. The more suddenly the power of the brain is arrested, the more decided and energetic is the spasmodic action, which always follows decapitation, excessive and rapid hemorrhage, strangulation, the action of hydrocyanic acid and other narcotic poisons, the inhalation of mephitic gases, and whatever prevents the arterialization of the blood. It is therefore manifest, that convulsions are owing chiefly to diminished power of the brain, (which cannot direct the locomotive organs with intelligence, unless supplied with good arterial

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of its expenditure in maintaining their activity, and the necessity of its renewal by respiration, which is therefore less essential to mammalia than to insects and birds, and still less essential to the imperfect vitality of cold-blooded animals.

blood,) and not to the "influx of a nervous fluid into the muscles," as supposed by Boerhaave,—nor to "a preternatural energy of the cerebral functions," as maintained by Bichat,—nor to some peculiar condition of the ganglionic nerves, as imagined by others.

The true theory of all spasmodic diseases must be sought in a loss or deficient supply of animal heat, diminished circulation and a vitiated condition of the blood, by which the brain and nerves are prevented from guiding and restraining the actions of the voluntary muscles,—as in the convulsions of hysteria, the contortions of chorea, the more obstinate spasms of tetanus, hydrophobia, epilepsy and cholera,—or the cramps that often follow immersion in cold water, and the universal tremours which attend the cold stage of fever. When I come to treat of these maladies in detail, it will be seen that the immediate exciting cause of all such actions, is deficient vitality of the blood, which in all the worst forms of cholera, epilepsy, apoplexy and even ague, presents the dark venous hue in the arteries. And although still adequate to maintain the contractile power of the muscles, it can no longer endow the brain with sensorial energy to control their movements. So greatly are the vital properties of the blood deranged in the latter stages of tetanus and hydrophobia, that when drawn from the body it refuses to coagulate, as we are informed by Cullen, Magendie and other accurate observers. The object of the physician should therefore be, to restore its healthy properties by pure air, artificial inflation of the lungs, the warm bath, when the circulation is languid, genial tonics and suitable nou-

rishment. *A still more important requisite is, to prevent that fatal condition of the blood which constitutes the leading symptom of all malignant diseases;* for when it has been once thoroughly disorganized, the springs of life are vitiated at the fountain head.

As the nervous system is more readily deranged by morbific agents, than any of the other organs, so are its functions most easily deranged in men whose nervous organization is highly developed, by whatever diminishes the quantity of respiration, or impairs the vitality of the blood,—whether it be impure air, deficient or improper nourishment, too little or too much exertion, intemperance, the depressing emotions, &c. Hence it is, that in all ages, men of genius have been subject to fits of great mental depression, or hypochondria,—a disease that belongs especially to the poetic temperament, and is perhaps common to all individuals whose vital energy is not equal to their boundless sympathy with nature, and burning intensity of desire to render their fellow-beings wiser and happier. Such were Dante, Petrarch, Tasso, Luther, Melancthon, Kepler, Shakspeare, Pascal, Milton, Newton, Johnson, Cowper, Burns, Rousseau and Byron, with many other "kings of thought and song,"—who in the midst of adversity, affliction and persecution, became immortal lights in the firmament of mind, that shall shine brighter and brighter, until knowledge shall become the universal inheritance of mankind, and banish innumerable evils that now exist in the world,—the greater portion of which are owing to ignorance in regard to the physical and moral laws of the universe.

But, alas! how many brave spirits have perished in the conflict with prejudice and blind custom!

The most important discovery ever made in the physiology of mind, was the plurality of the cerebral functions by Dr. Gall and his disciples, who have demonstrated that the perceptive, reasoning and moral faculties in man, depend on the anterior and superior portions of the brain; and the propensities or passions, as they have been called by metaphysicians, on the lateral, inferior and posterior divisions of the sensorium. Whether the numerous subdivisions of these more general ones have been accurately ascertained, must be determined by a more extended induction from facts. When physiologists shall have traced the connection between the nervous organization of all animals in which it exists, with the various degrees of their intelligence, passion and instinct, the mysteries of the nervous system will be resolved, and the physiology of mind be transferred from the hyperphysical to its appropriate rank among the exact sciences.

In regard to the double function of the nerves, it was long ago taught by Herophilus and Erasistratus, that some are designed for sensation alone, and others for the purpose of regulating the voluntary movements of the body. This theory has been submitted to the test of experiment by the late Sir Charles Bell, Magendie, Mayow, Müller and other physiologists, who, although they differ on some points, maintain that the nerves arising from the posterior portions of the spinal marrow, including the optic and olfactory nerves, branches of the fifth, seventh, eighth and ninth

pairs, are destined for sensation; while those arising from the anterior portions of the spinal marrow, like the third, fourth, sixth, and branches of the fifth, seventh, eighth and ninth, are regarded as voluntary or motory, and wholly destitute of sensibility.

But as yet, the discrepancy between the results of different experimenters, and even of the same individuals, leave it more than doubtful whether there be any such thing as insensible nerves. For Magendie has arrived at the conclusion from more recent experiments, that "*the roots of the sensitive and motor spinal nerves are equally sensible when they are both entire.* But if the sensitive nerves be cut, the motor immediately lose their sensibility. And if the motor nerves be cut across at the middle of their roots, the end which remains attached to the spinal cord is perfectly insensible, but the other end (next the ganglion) preserves an extreme sensibility." (*Medico-Chirurgical Review*, No. 62, p. 577.) Some physiologists maintain that the anterior spinal root is slightly sensitive, owing to an anastomotic filament which it derives from the posterior root. Nor is it easy to comprehend how impressions conveyed to the brain through the external senses could be transmitted to the voluntary muscles so as to direct their movements, if wholly destitute of sensibility. And although it is highly probable, that one set of nerves may perform the office of conveying information to the sensorium, and another set that of transmitting it to the locomotive organs, it is manifest that without sensation there could be no consciousness, memory and volition, all of which must therefore be modifications of one and the same power, dif-

fering, however, according to the various parts of the nervous system in which it is exerted.

For example, there is a striking difference between the *sensations* of feeling, hearing, seeing, smelling and tasting. Yet they are all *excito-motory*, and may be resolved into the tactual agency of material particles. The auditory nerves are excited by the tactual influence of the atmosphere in a state of vibration, exerted on the tympanum, by which an endless diversity of words of definite meaning are conveyed to the *sensorium commune*, and the voluntary organs directed how and when to move. Seeing is produced by the tactual agency of light on the optic nerve, and the visual impressions are transmitted to the locomotive organs. And so of feeling, taste or odour, all of which are specifically different sensations, that are modified in a vast variety of ways, by the particles of material bodies acting on the nerves of feeling, taste and smell. But how is it possible that any set of nerves could transmit these different sensations, if not endowed with sensibility? And if such were proved to be the case, I should still maintain, that unless duly supplied with arterial blood, they could be neither sensitive nor motory.

In regard to the office of the spinal marrow, a new theory has been proposed by Dr. Marshall Hall, who admits with other physiologists, that the brain and its nerves are for the purpose of endowing animals with sensation, perception, judgment, memory and volition; but maintains that *in the functions of the true spinal marrow there is no sensation, no consciousness, nothing psychical:*—that it presides over respiration, degluti-

tion, nutrition, reproduction and the action of the sphincters,—that it *is the source of animal life,* gives tone to the muscular system, and is the seat of all convulsive diseases; and yet that it is, in a peculiar sense, the seat of the appetites and passions.* (*Memoirs on the Nerv. System*, p. 70; *Lancet*, February, 1835, p. 686.) It would be useless to attempt a formal refutation of a theory that contradicts itself, and which is in fact unanswerable, because unintelligible. For if it be true, that in the functions of the spinal marrow there is no sensation nor consciousness, how can it be the seat of the appetites and passions? Or if respiration and the action of the sphincters be not subject to the voluntary power of the brain, why is it that during apoplexy, coma, typhus and concussion of the brain, respiration is nearly suspended, and the sphincters so far relaxed that the discharges are involuntary?

Whenever the temperature of warm-blooded animals is reduced 20° or 30° below the natural standard, by surrounding them with ice-cold water, the blood loses its florid hue, the surface becomes purple or livid, the action of the heart languid, the secretions are arrested, the brain refuses to perform its office, and the voluntary muscles are seized with spasms, or become paralytic, without the loss of oxygen, electricity or any other agent, except caloric; and if kept long in this situation, the heart ceases to beat, the crimson

* But in the *Lancet* of November 21, 1840, he informs us, that "life results from the pressure of arterial blood within the vascular structure of the different organs; or that life, in a word, is arterial blood."

tide of life to run, and all the powers of motion are at an end. The graceful form of the rounded limbs is exchanged for sharp or prominent angles, the cheeks become pale and shrunken, the lustre of the speaking eye is gone, the brightness of fancy is quenched, and the "thoughts that wander through eternity" are lost in the night of death.

What then would be the effect of immersing the human body in a bath of mercury, at the temperature of 30° below 0°? One spasmodic effort would close the scene,—and there would not be a drop of *living* blood in the system.* Where then would be "the vital spark of heavenly flame,"—the *Archeus* of Paracelsus, the *animal spirits* of Descartes and others,—the *pneumatical body* of Bacon,—the *ether* of Newton,

* An answer to the above question has been recently attempted by Dr. N. S. Davis, in an article on the *Philosophy of Medicine*, published in the *New York Journal of Medicine*, in 1847. After taking to himself no small share of credit for "avoiding the effort so often made in vain to find out the nature of the vital principle," he observes in a tone of triumph, that "life would be extinguished quite as soon by plunging a man in a bath of mercury at the temperature of 662° above, as at 30° below 0°: and if the latter experiment proves that caloric is the life-supporting agent, the former must prove it equally the life-destroying agent." Unfortunately for this ingenious logic, it proves too much; for if raised to 662°, steam would cause the boiler to burst, and the motion of the machine would be arrested, with as much certainty as if the fire were removed from the furnace. It follows therefore, according to the reasoning of Dr. Davis, that *caloric is not the cause of motion in the steam engine, Q.E.D.* I marvel that he did not represent caloric as the principle or cause of death; since there is an excess of heat in nearly all febrile and inflammatory diseases.

—the *anima* of Stahl,—the *nervous fluid* of Willis, Baglivi, Hoffman and Cullen,—the *irritability* of Glisson,—the *vis insita* and *vis nervosa* of Haller,—the *materia vitæ* of John Hunter,—the *vis vitæ* of Gœrtner,—the *excitability* of Brown,—the *nisus formativus* of Blumenbach,—the *sensorial power* of Darwin,—the *organic spirit* of Pring,—the *conservative principle* of Blane,—and the *vis medicatrix naturæ* of so many authors? Would this sudden loss of motion, sensation and intelligence be owing to the abstraction of some unknown hyperphysical entity, or of that spiritual fire which actuates the universe?—

> Warms in the sun, refreshes in the breeze,
> Glows in the stars, and blossoms in the trees!

If then it be true, that the quantity of life throughout the earth be in proportion to the heating power of the sun, what, I repeat, is the use of animal heat? Is it not the essential character of a *vera causa*, that its power should be proportional to the effects it produces, and that the latter should cease in its absence? Is it philosophical to assume the existence of any more causes than are sufficient to explain the phenomena? Or if an immaterial and unknown principle of life be still admitted, will it explain anything in the absence of caloric? It is impossible to blink these questions, or to resist the conclusion they naturally force upon the common sense of every unbiased mind, that caloric is not only the cause of all excitement, but directly or indirectly, of *excitability*,—that it is not only the most potent and universal stimulant in nature, but the cause of *sensitiveness*.

Let us now proceed to trace the natural order in which the different functions depend on each other, and the manner in which all the organs are united into one harmonious system. As it is already understood that the action of the heart is owing to the same cause on which all the moving powers of the animal economy depend, I shall proceed to show that it is derived from the lungs by respiration, to which all the other functions are subordinate, and not from an inherent property of the muscular fibre, as maintained by Haller; nor from an inherent *propulsive force*, as maintained by Tiedemann.

It was long ago ascertained by Hunter, that after the heart of a recently killed dog had ceased to contract, its pulsations might be many times renewed by artificial inflation of the lungs, at intervals of eight and ten minutes—a fact which has been since verified by the experiments of Brodie and many others. Bichat was also fully aware that respiration is essential to the movements of the heart; but so confused were his notions, that he observes, in his *Researches on Life and Death*: "the heart ceases to beat when the chemical function of the lungs is arrested, *because black blood is not of a nature to keep up its action.*" Again, it is said by Müller, that "the nature of the cause of the heart's action cannot be determined in the present state of our knowledge." (*Elements*, p. 188.)

It is generally admitted by physiologists, that blood is the proximate exciting cause of the heart's action. But that the caloric evolved in the lungs enables it to produce this effect, is evident from the fact, that when

removed from the body, and even deprived of blood, its contractions may be many times renewed and suspended, by successive elevations and reductions of temperature, without the influence of oxygen, electricity or any other known agent. As an example of this, it was observed by Bacon, that the heart of a criminal who had been executed for high treason, when thrown into the fire, contracted with such force as to leap up seven or eight times, to the height of about eighteen inches at first. (*Hist. of Life and Death.*) It was also ascertained by John Hunter, that when three pieces of muscle were taken from the neck of a recently killed sheep, and placed in water at different temperatures, they contracted sooner and more firmly, in proportion to the quantity of heat applied.* Nor

* With 'a view of ascertaining the correctness of his results, I took three pieces of muscle from the neck of a sheep just bled to death, each of them an inch and a half in length, and put them into separate vessels of water, at temperatures of 80°, 110° and 120°, when the one in the first vessel contracted one-third of an inch in three minutes ; the second, one-half an inch, and the third three-quarters, in one minute and a half. The experiment was then varied by placing another piece of the same dimensions in a freezing mixture at 17°, when it scarcely contracted at all, and was quite frozen in seven minutes. But when transferred to water at 120°, it slowly shortened from one and a half to half an inch. In accordance with these facts, it was found by Mr. Clift, that by the application of hot water, the heart of a carp was made to contract eleven hours after decapitation ; and that the muscles of another carp were thrown into a state of violent contractions by the same means, for hours after the brain and spinal marrow had been destroyed. Similar results were obtained by Mr. John Marshall, at my request, in 1840. For he found that, forty-five minutes after the vessels of the neck of a tortoise had been divided, the

was he ignorant that the blood itself when removed from the body, and therefore from all nervous influence, undergoes contraction, as in the process of coagulation; and that this contraction is hastened by an elevation of temperature. Yet it seems never to have occurred to this great man, that caloric is the active principle in the blood; nor that if the temperature of the whole earth were reduced to 32° for any considerable time, there could not be a vestige of life on its surface.

Corresponding with the large amount of caloric derived from the atmosphere by the respiration of birds, the pulsations of the heart are stronger and more frequent than in mammalia, *cæteris paribus*,—varying from one hundred and ten, to one hundred and fifty, and even two hundred per minute in the smaller and more active species. So rapid is their circulation, that when the vessels of the neck are divided, nearly all their blood escapes in about half a minute; but requires from one and a half to two minutes, in the dog, sheep, deer, hog and other mammalia: whereas in man, whose mean temperature is several degrees lower, the pulsations of the heart are less vigorous and frequent. For it has been found to

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pulsations of its heart were augmented from nineteen to thirty-six per minute, on raising its temperature from that of his room to 90°; that on applying water cooled down to 60°, they were reduced to seven beats, but augmented to fifty-two on raising the water to 106°, and again reduced to twenty-two per minute, on cooling the water to 90°. The heart was then removed from the body, and exposed to the alternate influence of warm and cold water, with similar results, which were also observed on the heart of a salamander.

discharge about two ounces of blood from the ventricles at each beat, more or less, according to the energy of the constitution, size of the organs, &c.; so that if it contract seventy times per minute, it follows, that from twenty to thirty pounds of blood, or all which the body contains, must circulate throughout the lungs and general system in from two to three minutes.

But so languid is the circulation in reptiles and fishes, that when decapitated or deprived of the heart, their cold, pale, watery and imperfectly organized blood, oozes out by drops; and is often many hours in escaping from the system in sufficient quantity to destroy life, especially during cold weather.* Again, whenever the temperature of the human body is raised above the natural standard by immersion in the hot bath, the pulsations of the heart are augmented from seventy or eighty to one hundred and forty or more per minute, which is also the case during the hot stage of inflammatory fever. On the other hand,

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* Caldesi found that the heart of a tortoise contracted from thirteen to twenty times per minute; while Wilford observed that in the boa, the pulsations varied from fifteen to twenty-five per minute; and Fontana found them from ten to fifty in the frog. But their number and force depend on the temperature of the surrounding medium. For at 47°, Spallanzani observed the heart of a serpent to perform ten or twelve beats; but twenty-eight or thirty beats when the air was at 65° and 70°; while others have found, that on the approach of winter, they are sometimes reduced so low as one beat in two minutes. And Dr. Whytt states, that on raising the temperature of a frog to that of the human body, its pulsations augmented from twenty-five to eighty-seven per minute.

when reduced below the natural standard, as during the cold stage of fever, or by immersion in the cold bath, the force and frequency of the heart's action are greatly diminished. For example, it was observed by Dr. Currie, that on plunging a patient in water at 36°, his temperature soon fell to 87°, when the pulse became nearly extinct. So greatly is the pulmonary circulation paralyzed in such cases, that very little carbon and hydrogen are given off in the air-cells of the lungs; the supply of animal heat by respiration is nearly suspended; and if the circulation be not speedily restored by the warm bath, the patient remains chilly for two or three days, even before an ordinary fire.

The same thing occurs during asthma, and that congested state of the lungs which exists in the early stages of tubercular consumption. It has also been observed, that during the cold stage of cholera, and some of the more malignant forms of algid fever, the temperature is often reduced from 10° to 20° below the normal standard, when the blood, even in the arteries, assumes a dark venous hue, and the general circulation is so far diminished, as to resemble the languor of cold-blooded animals, with a frightful prostration of all the vital functions. In all cases of languid circulation, from whatever cause produced, we should apply that remedy on which its healthy vigour depends. By means of the warm bath, we can arouse the circulation of the whole system; and when the stagnant blood is dark coloured, we can change it to a bright florid hue, accelerate its passage through the lungs, and thus augment the function of respiration;

many of the lower animals which have no heart, is active during summer, checked by cold nights, and wholly arrested during winter:—2. That the circulation of chyle through the lacteals, and of lymph through the absorbents, is obviously independent of the heart's action; and like that of the blood, is in proportion to the healthy temperature of animals; being more rapid in birds than in mammalia; languid in cold-blooded animals; and suspended in all by intense cold, or by arresting the supply of caloric by respiration:—3. That after decapitation and removal of the heart from rabbits, or placing a ligature around the aorta, the blood has been seen with a good microscope, to move with considerable velocity through the capillaries of the mesentery for thirty-five minutes, and in one case for an hour and a quarter, as proved by the experiments of Dr. Philip:—4. That in many cases after death, and apparent cessation of the heart's action, the large arteries have been found empty; all their blood having been conveyed to the veins by capillary attraction: and, 5. *That after the amputation of a limb, and the stoppage of its capillary circulation, the motion of its blood may be restored, and carried on with considerable activity for fifteen minutes, by the application of heat*, as proved by the experiments of M. Guillot. (*Journal de Physiologie*, tome xi. p. 170.)

It has been urged by De Saussure, Decandolle, Tiedemann and others, that the circulation in plants and

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view then which seems capable of explaining the phenomenon, is that of an attraction between fluids and solids, whether we call it capillarity, endosmose, exosmose, vital affinity or by any other name.

animals must be owing to a different cause from that of ordinary capillary attraction, because when their vessels are divided during the living state, sap and blood continue to flow from them; whereas the fluids drawn up by small tubes of glass and other dead matter are not expelled from their upper orifices. But it should be observed, that the force of capillary attraction, *cæteris paribus*, is always inversely as the diameter of the tubes, which in most of our experiments, varies from the one-twentieth to the one-hundredth of an inch; whereas the intestines and capillary tubes in the tissues of plants and animals have diameters from $\frac{1}{2540}$ to $\frac{1}{5080}$ of an inch, according to recent observations with the microscope. Hence the great force with which the sap issues from the stump of a cut grape-vine, as shown by the experiments of Mirbel and Hales, who found it equal to the pressure of 34 and 38 inches of mercury.* And such is the *vis a tergo* generated by the capillary circulation of chyle and lymph through the absorbents, that when the thoracic duct of a dog is secured with a ligature below the subclavian vein, it has been known to burst from the pressure. This has been proved by the experiments of Horne, Autenrieth, Tiedemann and Carus, cited by Müller. (*Elements*, vol. i. p. 284.) In all

* It has been long known, that when a plant is put in the ground, its roots will extend only in the direction in which they can obtain nourishment; and that when placed in a dark room, with a hole in the wall to admit light, it gradually extends or grows in that direction. Nor is the latter fact more surprising, than that solar influence should be the cause of growth throughout the vegetable creation.

such cases, the *vis a tergo* is generated by virtue of an attraction between fluids and their containing vessels; the former being plus, and the latter minus. The organic particles of blood are forced through the pores of the systemic capillaries, and combined with the several tissues, by virtue of the same attraction. And it has been found that the worn-out particles of the solids are not taken up by the mouths only of the lymphatics, but are absorbed by the pores of their coats; and finally, that neither in plants nor animals is any contraction of their capillaries essential to their circulation.

CHAPTER V.

THEORY OF DIGESTION, SANGUIFICATION, COAGULATION, SECRETION, NUTRITION, MUSCULAR MOTION, SENSATION, ETC.

"The idea of vital forces may gradually become so clear and definite as to be available in science, and future generations may include in their physiology propositions elevated as far above the circulation of the blood, as the doctrine of universal gravitation goes beyond the explanation of planetary motion by epicycles."—WHEWELL.

IN accordance with the prevalent doctrine of the schools, Dr. Prout maintains, that "the true and legitimate object of inquiry for the physiologist ought to be, *not what the vital principle is*, but what it does, just as the laws and effects of gravitation are legitimate objects of inquiry, though we know nothing, *and probably never will know* anything of the principle of gravitation." (*Application of Chemistry to Physiology.*) Such, however, was not the opinion of Sir Isaac Newton, who made repeated efforts to ascertain the cause of gravitation, cohesion, chemical affinity and animal motion, all of which he referred to one and the same cause. Yet it is maintained by Berzelius, Tiedemann, Müller, Liebig and more than an hundred other physiologists of the nineteenth century, that "the vital principle is a power distinct from all the other powers

in nature;" while Dr. C. Holland adopts the hypothesis of Bichat, Richerand, Magendie, Prichard, Fletcher, *cum multis aliis*, that "life is not a simple principle, but the result of compound principles and actions, pervading and common to every part of nature." (*Laws of Organic and Animal Life*, p. 355.) Alas! the contradictions and mysteries of science are scarcely less perplexing and prejudicial to the interests of mankind than those of metaphysics and scholastic divinity.

> "For 'tis not only individual minds
> That habit tinctures, or that interest blinds;
> Whole nations, fool'd by falsehood, fear or pride,
> Their ostrich heads in self-illusion hide."
>
> THOMAS MOORE.

The earliest theory of digestion that has come down to us is that of Hippocrates, who regarded it as a species of concoction analogous to the ripening of fruits by solar heat.* The same view was adopted by Ga-

* Plato also, in the *Timæus*, represents heat as the cause of digestion, of the diffusion of blood throughout the body, of nutrition and growth, which he attributed to the union of similar parts, that have an affinity for one another. (Chap. 57.) Aristotle likewise declares expressly, in his *Treatise on the Soul*, that heat is the cause of concoction. (Lib. ii. c. 4.) The doctrine of the early Greek physicians, that food is cooked in the stomach, was rejected by Asclipeades, who maintained that the process is merely one of *solution* into very minute parts. (LE CLERC, *Hist. de la Médecine*, p. 408.) But solution is only an effect of heat, or a stewing process. According to Erasistratus, digestion is a triturating or grinding process, performed by a contraction of the stomach on its contents. It was in reference to these ancient theories, that Dr. James Gregory said to his class: "Gentlemen, some tell us the stomach is a *stew-pan;* others, that it is a *mill;* and others again,

len, and taught by nearly all his successors, down to the time of Paracelsus and Van Helmont, who referred it to the agency of an acid liquor, under the control of the *Archeus*, which was supposed to be endowed with intelligence, to direct the stomach when to allow its contents to pass into the duodenum, to give the alarm and cause it to expel whatever is noxious, and to preside over all those actions of the living body that constitute the *vis conservatrix naturæ.* But I have already shown that the *Archeus* was only another name for the *Φυσις* of Hippocrates; while it is equally evident, that the *fermentation* and *maceration* of the chemical physicians were merely different names for *coction*, which means an action produced by caloric, from *coquo*, to heat, to boil, to cook, to digest, to ripen, &c. With the exception of the mechanical physicians, who maintained that digestion is the result of *trituration* by the coats of the stomach, the chemical theory prevailed until the time of Boerhaave, who, like a genuine eclectic, referred it to the united agency of *gastric liquor, nervous influence and animal heat.*

Since the time of Boerhaave, physiologists have generally maintained that food is converted into chyme by the solvent power of gastric juice, but under the immediate influence of "the unknown vital principle," which some have identified with the unknown nervous fluid, and others with the equally unknown electric fluid.* That nervous influence is

that it is a *fermenting vat.* But I say, gentlemen, *it is a stomach.*" Whether this facetious account of the matter was intended to silence inquiry, is left to the decision of competent judges.

* Those who have adopted the electrical theory of life, have vainly attempted the explanation of one mystery by resorting to

not essential to the process, (further than as it governs the voluntary function of respiration,) has been sufficiently proved by the experiments of Brodie, Magendie, C. Holland, Mayer, Brachet, Leuret and Lassaigne, who have shown that in the horse, dog and rabbit, the nerves going to the stomach may be divided without arresting the secretion of gastric juice, or seriously retarding the process of digestion.

Nor have we ever had the slightest proof that electricity is essential to the process; for the experiments of Dr. Philip have been repeatedly proved to be fallacious, and therefore require no comment.* But that

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another. And so highly developed is the organ of wonder, compared with the reasoning faculties, that in all ages the mass of mankind seem to have entertained a profound reverence for what they did not understand, as if simplicity were not the highest attribute of excellence, beauty and truth. It is also gratifying to the selfish pride of inferior minds, to perceive that there are mysteries which reduce the loftiest intellects to an equality with themselves. With such persons, the simplicity of a new discovery derogates from its importance, being apparently so clear and obvious, that they only wonder how it ever could have escaped their own sagacity. It has been supposed that during respiration, the blood acquires electricity, which is distributed by the pneumogastric and sympathetic nerves to the great nervous centres, which, becoming thus charged, excite the action of any organ, by giving a spark to the nerve that supplies it. But in the new experiments of Person and Müller, no signs of electricity could be detected by the finest galvanometer in a nerve, at the moment when some charge, consequent on its irritation, and transmitted along it, was exciting a muscle to contract. (*Alison's Outlines of Physiol. and Pathol.*, p. 117.) The fact is, that all nerves are bad conductors of electricity, as Bischoff has shown.

* The impression that electricity is in some way connected with digestion and all other vital phenomena, has been inferred from the fact, that the *gymnotus, torpedo* and *silurus*, have the power of

caloric is the principal agent on which the solvent power of gastric juice depends, would appear from a variety of considerations. 1. We have seen that digestion is far more rapid in birds than in mammalia, and more rapid in the latter than in cold-blooded animals. 2. It has been proved by the experiments of

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communicating an electrical shock; and that after having imparted several shocks, the power of digestion is greatly diminished. But the circumstance alone of this power being confined to a very small number of animals, and these of a low grade in the scale of organization, proves that it is not essential to any of the vital functions. Like the nauseous secretion of the pole-cat, and that of some insects, it was doubtless intended by nature merely as a means of defence. Besides, electrical fishes have always been found in warm climates, and cannot exert their peculiar faculty when exposed to a low temperature. It was observed by John Hunter, that the electric columns of the torpedo were largely supplied with blood-vessels, and he found that they were not essential to any of the processes of life except the preservation of the electrical power. Dr. Davy observed that the electric columns are connected with the organs of respiration. It was also the opinion of Humboldt, that the electrical power of the animal is proportional to the activity of respiration and nutrition. It may therefore be inferred, without departing from the rules of philosophic induction, that such animals have the power of converting at will a portion of the caloric obtained by respiration into the temporary form of electricity. Nor is this more strange than that the caloric of atmospheric vapour should be discharged in the concentrated form of lightning. Some have supposed that the lungs are positive, and the stomach negative; while others have prescribed copper and zinc filings, with dilute nitric acid, with a view of supplying the patient with galvanic electricity. But, as Prof. Schœnbein observes: "So long as we are without an exact idea of what electricity is, the different modes of its development will, of course, be incomprehensible, and we shall scarcely be able to say anything upon the cause of animal electricity, however carefully the structure of the fish may be studied." (*Noad's Lect.*

Dr. Beaumont, that when gastric juice is taken from the stomach, and kept in vials at the temperature of the body, it converts aliment into chyme; but that when kept below the temperature of 40°, it produced no further change than so much water. 3. That the digestive power of man is in proportion to the quantity of his respiration, which is augmented by moderate exercise and agreeable emotions, but diminished by repose and the depressing passions. 4. That when the circulation is weak, digestion is wholly arrested by taking large quantities of cold drinks, which often produce flatulence, colic and nausea. The danger of drinking cold water when exhausted by over-exertion, is well known in warm climates, where it often destroys life suddenly. Dr. Beaumont states, that on giving to St. Martin a gill of water at 55° when the stomach was empty, its temperature was reduced from 99° to 70°, at which it stood for a few minutes, and did not regain its normal standard until thirty minutes had elapsed. Cholera morbus, gastritis, enteritis, dysentery and diarrhœa, are often produced by cold drinks, ice-creams, &c., during hot weather.

The next step in the process of assimilation, by which aliment is prepared to nourish the solids, takes place in the duodenum, where the albumen, oily matter, and white globlues of chyme are converted into chyle, by uniting with pancreatic juice and a very large proportion of bile; while the resinous or bitter portion of the latter combines with the excrementitious part of the aliment, to be conveyed into the intestines, being never found in the lacteals. But whenever the chemical function of the lungs is greatly diminished, and the temperature of the body reduced

from 5° to 10°, as during the cold stage of many fevers; or even 20°, during the later stages of malignant cholera, and in those algid forms of disease termed cold plague, the secretion of gastric liquor, bile, pancreatic juice, urine, perspiration and other animal fluids, is almost wholly suspended.

During the progress of chyle through the duodenum and lacteals to the thoracic duct, it becomes further and further organized, or assimilated to the nature of blood. For it has been found that, besides albumen, oily matter and white globules, it contains more or less fibrin, that coagulates slowly. But it is not until it passes through that wonderful laboratory of life termed the lungs, that it assumes the colour and vital properties of blood, which contains the proximate constituents of all the organs ready formed, including most of the secreted fluids. By giving off variable proportions of carbon and hydrogen, that unite with atmospheric oxygen, caloric is evolved, and a portion of nitrogen absorbed, by which chyle is transformed into living blood of a bright scarlet hue, its temperature elevated from 1° to 3° in the higher animals, and its solid particles augmented from three to fourfold, according to the analyses of Vauquelin, Tiedemann, Gmelin, Reuss and Emmert.

How transcendently beautiful is the mechanism by which grass, corn, fruits and a multitude of aliments, all differing in their composition, are thus converted into the constituents of animals, endowed with the power of renewing their organization and of maintaining the activity of all their functions! The art of man has scarcely yet succeeded in ascertaining the proxir tuents of gastric juice, bile, pancreatic

liquor, chyme, chyle and lymph. How then is it possible that he should imitate the exquisitely refined chemistry of nature by which blood is formed? We have not even approached the perfection of that amazing process of living combustion, by which the temperature of animals is maintained at an uniform standard,*—much less the admirable provision of nature by which just so much carbon and hydrogen are given off in the lungs, and just so much nitrogen absorbed, as are requisite for the formation of blood. Nor is it possible to rival the chemistry of life, so as to produce blood, bile and gastric juice, without a special mechanism for the purpose, such as that of the lungs, liver and stomach.

But that the caloric obtained from the atmosphere by respiration is the organizing principle by which blood is formed, would appear from all the analogies of nature. In the first place, if it be true, that solar caloric is the cause of organization and growth throughout the vegetable world, animal heat must perform the same office in the higher grades of existence. As the abundance, diversity and richness of vegetation depend on the mean temperature of climates, so will it be seen from the table, constructed from the analyses

* By the discovery of such a method, including the combustion of all that valuable fuel which now passes off in the form of smoke, four-fifths of the capital now wasted in the creation of artificial warmth would be saved. And could we devise a method of conveying caloric through our dwellings, in a mode resembling that by which it is diffused through every part of the body from the lungs, in combination with arterial blood, the saving would be still further increased, an equable temperature maintained, and many of the diseases that afflict the human race be prevented.

of Prevost and Dumas, Denis, Le Canu, Berzelius and Marshall, that the ratio of solid organic matter in the blood of different animals is in proportion to the quantity of their respiration and mean healthy temperature, *cœteris paribus*,—being greater in birds than in mammalia, greater in the latter than in reptiles,* and greater in reptiles than in fishes. In accordance with this fact, we learn from the accurate researches of Dr. John Davy, that the specific gravity of the blood in these four classes, varies in the following proportions:—

	Arterial.	*Venous.*
Turkey	1061	——
Lamb	1047	1050
Dog	1048	1053
Frog	1040	——
Codfish	1034	——

But there is reason to believe from the experiments of Denis, Le Canu, Marshall and others, that the

* Prevost and Dumas found the blood of a tortoise, which had been five months in a state of lethargy, to contain 15·06 per cent. of solid matter, owing, as they rightly supposed, to the loss of a large proportion of water by exhalation or transudation. And it will be seen hereafter, that owing to the same cause, (transudation of serum or water,) the proportion of red particles is greater in many cases of malignant cholera, than during the most vigorous state of health. (*Examin. du Sang, Ann. de Chim. et de Phys.* vol. xxiii.) But Mr. Marshall was so kind as to perform some analyses at my request, which show that the blood of the tortoise, while in a state of activity, does not afford above eight per cent. of solid particles, and that of the salamander about 7·54. It may therefore be presumed, that the blood of all young birds hatched without feathers, and of mammalia born with the eyes closed, whose power of maintaining their temperature by respiration, is for some days very imperfect, is less highly organized than at later periods, correspondin feebleness of all their vital functions.

ratio of fibrin and red particles, is higher in the blood of birds and mammalia, than was represented by those of Prevost and Dumas. For on evaporating a mixture of arterial and venous blood of healthy pigeons to perfect dryness, by means of the moderate temperature, produced by a water bath, as in the process of Prevost and Dumas, Mr. Marshall obtained 20·41 per cent. of solid particles. There is also reason to believe, from the analyses of Denis, that the blood of the more active mammalia when in health and well nourished, is more highly organized than that of man. For with Prevost, Dumas and Le Canu, he found the latter to average about 13 per cent.; while the blood of the dog, calf, bullock and horse, afforded the mean of 16·40 per cent. of fibrin and hæmatozin;* as might be inferred from the size of their lungs, mean tem-

* Denis also found the blood of individuals with broad chests and great muscular power, to contain from fourteen to eighteen per cent. of fibrin and red particles; whereas in those of narrow chests and feeble constitutions, they varied from eight to eleven per cent. And as might be supposed from the larger size of the thorax in man than woman, his blood is richer in organic particles, in the ratio of 13·24 to 11·59, according to M. Le Canu. (*Études Chimiques sur le Sang Humain*, par Louis René Le Canu.) Coinciding with these facts, M. Quetelet represents the lumbar strength of the male as greater than that of the female, during the early periods of life, in the ratio of three to two; and after full growth, nine to five; while at fifty years of age, it is one-third less in both. And it will be seen hereafter, that whatever diminishes the process of respiration, whether a diseased state of the lungs, (as in asthma, pneumonia and phthisis,) low diet, loss of blood, the depressing passions, or protracted disease of any description, impairs the process of sanguification, with all the energies of life.

perature, and power of digestion, which I have shown to be greater than in man, *cæteris paribus*. In accordance with the above facts, Denis found the proportion of fibrin in the mixture of arterial and venous blood of the fowl, to be twelve parts in 1000; while in venous blood of the horse, it varied from five to six, and in that of man, from 2·9 to 4·3. He further states, that the ratio of red particles in the human species augments from infancy up to the adult state, but diminishes after the age of forty, up to seventy. (*Recherches Expérimentales sur le Sang Humain, etc.* par Prosper. Denis.)

Table Representing the Relative Proportions of Dry Coagulum, Albumen of Serum, and Water, found in the Blood of different Animals.

Names of Animals.	Coagulum.	Albumen of Serum.	Water.	Experimenters.
Pigeon, (venous blood.)...	15·57	4·69	79·24	Prevost and Dumas.
Do. art. and venous........	20·41	4·69	79·69	Marshall.
Hen, venous blood.........	15·71	6·30	79·99	Prevost and Dumas.
Do. art. and venous........	16·10	4·50	77·00	Denis.
Duck, venous	15·01	8·47	76·52	Prevost and Dumas.
Raven, venous...............	14·66	5·64	79·70	" "
Simia Calitriche, venous..	14·61	7·77	77·60	" "
Man, venous..................	12·92	8·69	78·39	" "
Do. vena portæ..............	11·44	8·44	80·14	" "
Maximum in Man, v......	14·84	6·76	77·86	Le Canu.
Do. in Woman, venous....	12·99	7·84	79·03	"
Average in Man, venous..	13·24	7·81	78·93	"
Do. in Woman, venous....	11·59	7·96	80·43	"
Sang. tem. in Man, v......	15·85	4·85	76·92	Denis.
Maximum do. venous......	18·87	5·28	73·80	"
Lymph. temper, venous...	9·27	5·90	82·00	"
Do. minimum, venous.....	6·33	5·40	86·90	"
Guinea Pig, venous	12·80	8·72	78·48	Prevost and Dumas.
Dog, venous...................	12·38	6·55	81·07	" "
Horse, venous................	9·20	8·97	83·79	" "
Calf, art. and venous......	9·12	8·28	82·60	" "
Sheep, venous................	9·35	7·72	82·60	" "

Names of Animals.	Coagulum.	Albumen of Serum.	Water.	Experimenters.
Do. art. and venous........	13·84	6·76	79·40	Marshall.
Three Kittens a day old..	12·95	5·25	81·44	"
Young Puppies..............	16·90	4·60	78·00	Denis.
Calf three weeks old......	15·80	6·30	77·50	"
Bullock two years old.....	17·40	5·00	76·30	"
Horse	15·30	6·00	78·65	"
Do............................	16·80	6·50	75·50	"
Sheep, venous...............	16·36	......	......	Le Canu.
Do. art.	17·07	......	......	"
Land Tortoise, a. and v. ..	8·02	6·90	85·02	Marshall.
Salamander, do............	7·54	6·16	86·80	"
Frog	6·90	4·64	88·46	Prevost and Dumas.
Trout	6·38	7·25	86·37	" "
Eel	6·00	9·45	84·60	" "
Loach	4·81	6·87	88·62	" "

From the analyses of Prevost and Dumas, Berzelius, Marcet, Denis, and his own, M. Le Canu represents the venous blood of man as composed of the following constituents:—

Dry crassamentum............................	130·8453	in 1000 parts.
Albumen of serum............................	67·8040	
Salts,* oily, extractive and other matters	10·0800	
Water	790·3707	
	1000·0000	

He also estimates the crassamentum as composed of

Albumen..	125·6373	in 1000 parts.
Fibrin	2·9480†	
Colouring matter..............................	2·2700	

* The proportion of salts in the blood, depends on the quantity contained in the aliment: and it has been found that above one-half of them consists of chloride of sodium, if we except the salts of lime, which enter into the composition of bone. But the office they perform in the functions of life is not well understood. Nor have the proportions of oily, phosphuretted and extractive matters, found in the blood, been ascertained with precision.

† From twenty-two observations, he found the proportion of dry fibrin to vary from 1·860 to 7·235 in 1000 parts of human venous blood.

From which it would appear, that the organic particles of blood are composed chiefly of albumen, with a small proportion of fibrin, both of which are radically identical, according to Denis. As an example of the highly complex character of their proximate constituents, we are informed by Liebig, on the authority of Mulder, that the equivalent of albumen, as it combines with oxide of silver, is 7447, and that of fibrin, as it combines with hydrochloric acid, the oxides of lead and copper—6361.* (*Organic Chemistry*, vol. i. p. 339.)

The blood of all animals is formed from the same primitive elements; but as the different orders obtain various quantities of caloric from the air by respiration, its organic particles vary in form and magnitude, being elliptical in birds, and larger than in mammalia, yet larger in reptiles, fishes and other cold-blooded animals than in either.† The consequence of which

* Liebig observes, that the readiness with which the complex molecules of organic matter decompose, is owing to the large number of atoms that enter into their composition, and the numerous directions in which their attractions operate, (*page* 323.) But I have shown that the tendency of the primitive atoms to unite into complex molecules, depends on the quantity of caloric around their particles, as no other elements except oxygen, hydrogen, carbon and nitrogen, are capable of entering into such complex combinations. (See *page* 471.)

† Hence it is, that when the blood of mammalia is injected into the veins of birds, the latter die in a very short time, and *vice versa;* while the blood of reptiles and fishes is rapidly fatal to all the higher animals, in which the extreme capillaries are so small, that they cannot be seen without a good microscope; but they may often be discerned with the naked eye in cold-blooded animals. In regard to the colour of the red particles, nothing has been clearly ascer-

is, that their whole organization exhibits corresponding variations. Nor is this more strange, than that the form of crystals, and the chemical properties of many bodies composed of the same ponderable elements in the same proportions, should vary according to the temperatures at which they are produced, or the quantity of caloric around their particles, and the number of atoms that compose these particles. For it is self-evident, that whatever the organizing principle may be, it must determine the composition and arrangement of the molecules that form any part of the body,—modified, however, in an endless variety of ways by surrounding circumstances.

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tained, except that it is owing to an envelope surrounding white nucleii, from one-third to one-fourth the size of the blood corpuscles, according to Hewson; and which he supposed to be identical with the white globules of chyle. Some have referred their red colour to the presence of carbon,—others to iron or its oxide, because found united with the red particles, (in the ratio of about two drachms to 30 pounds of blood,) or of 5·6 parts of the pure metal in 10,000 parts of blood. But as both of these substances are found in chyle, which is white, and as the colouring matter of the blood has been obtained entirely free from iron, we must look for some other explanation, connected more immediately with the function of calorification. For it is evident that the depth of colour is in proportion to the mean temperature of animals, being brighter in birds than in mammalia, yellowish in reptiles and still paler in fishes, if we except the tunny tribe, (and a few others,) whose breathing apparatus is very extensive for their class; while in animals of a still lower grade, it is without any colour. In fact, Galen tells us, that like Plato and Aristotle, Praxagoras of Cos, (the master of Herophilus, and one of the first of the medical sect called Dogmatists,) maintained that the aliments we consume undergo various changes in the vessels, according to the different degrees of heat which they contain. (GALEN, *De Natural. Potent.*, L. ii.)

That caloric is the cause of sanguification, would further appear from the fact, that it is the obvious agent by which the eggs of birds, reptiles, insects, fishes and all other animals, are gradually changed from the state of a semi-fluid germ into blood and the various organs of which they are composed,—whether derived from the sun, by which the lower animals are hatched,—from ordinary combustion, as in artificial incubation, or supplied by the natural temperature of the parent, as in the ordinary process of hatching birds. Dr. Theodore Schwann was convinced by a series of his own experiments, that when surrounded by an artificial temperature at the proper standard, the development of the germ can proceed to a certain extent without oxygen, while surrounded with hydrogen or nitrogen, but not if exposed to carbonic acid. And some recent experiments of Mr. Towne, recorded in the fourth volume of the *Guy's Hospital Reports*, were by many persons thought to prove, that oxygen is not essential to the early development of the chick *in ovo*. For he found that after eggs were surrounded with strips of thin and dense paper, dipped in albumen, and then smeared over with varnish, the process of incubation went on without interruption, till the twelfth or thirteenth day, when kept at the temperature of 100°; and that the allantoid membrane was perfectly formed.*

* But in his able *Lectures on Generation*, (published in the *Lancet*, 1840,) Mr. Owen states, that when a solution of acetate of lead was introduced through an opening at one extremity of the shell, which was then carefully luted, covered over with paper dipped in albumen, and smeared with varnish, as in the experiments

Dr. Southwood Smith maintains, that chyle and venous blood are converted into the arterial state, by parting with carbonic acid and water in the lungs; in exchange for which, they receive oxygen and nitrogen. Müller also contends, that "oxygen combines imme-

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of Mr. Towne,—patches of black pigment, or sulphide of lead, were discovered on the internal surface of the shell, after exposing the egg for some time to the influence of sulphuretted hydrogen. He therefore contends that this gas must have found its way through the different layers of paper dipped in albumen, because they were changed yellow; and that air may percolate the coating of varnish, and afterwards find its way to the internal parts of the egg through the layers of paper. I have also observed that the blood going to the respiratory membrane is of a dark venous hue, and returns of a scarlet colour,—proving that, to a certain extent, it undergoes the same change as while passing through the lungs, after leaving the shell. But we are greatly in want of additional experiments for ascertaining with precision, what amount of carbonic acid is thus generated and exhaled through the pores of the shell during the various stages of incubation,—in short, what is gained and what is lost. Wagner states, that during the first week, the egg loses five per cent. of its weight, thirteen per cent. the second week, and sixteen per cent. during the third week. (*Elements of Physiology*, p. 129, trans. by Willis.) This loss of thirty-four per cent. is doubtless owing to the exhalation of water, and to the giving off of carbon and hydrogen, that unite with the oxygen absorbed, by which the albumen of the egg is converted into blood, in the same way that chyle is changed into blood by giving off water, carbon and hydrogen, while passing through the lungs, viz., by the creative process of living combustion. Since the first edition of this work was printed, Baudrimont and Martin Saint Ange have announced as the result of their experiments, that during incubation, the small red globules do not appear in the embryo, nor is the latter developed unless there be an absorption of oxygen through the shell, and an exhalation of carbonic acid. (MATTEUCCI, *Phenom. of Living Beings*, p. 139.)

diately with the blood, and enables it to excite the various tissues." But if oxygen were the animating principle, it ought to excite the heart and other muscles to contract when removed from the body, which is not the fact; for when reduced to the temperature of 32°, it produces no more effect upon them than so much carbonic acid. And although electricity excites contractions for a short time, they are spasmodic, and its influence is exceedingly partial, compared with the same agent in the form of caloric.

Moreover, it has been fully established by recent researches into the phenomena of generation and growth of the embryon, that in no case is arterial blood transmitted from the mother to the fœtus through the vessels of the placenta, which serves chiefly as a *reservoir* of nourishment, supplied by the mother, absorbed by the vessels of the fœtus, and converted into blood that is wholly different from that of the mother,—in short, that the embryon is nourished by the transudation of arterial blood from the vessels of the mother. According to Müller, the colour of fœtal blood is the same in both arteries and veins. This much may be asserted with confidence, that it is not by means of oxygen, or any other *ponderable gas*, that the proximate constituents of the egg are converted into the blood and different organs of the chick; and that as the germ of viviparous animals is formed from an albuminous secretion, before any connection is established with the circulation of the mother by means of the placenta, it can receive no oxygen from the maternal blood; consequently, that it must be developed by means of the same life-giving element

(Ζωηφορον) that actuates the universe, and fills it with beautiful creations; that causes the germination of plants, the circulation of sap, and its conversion into the various constituents of their substance while passing through the leaves, (where oxygen is not absorbed but given off;) and by which the Egyptians annually produce one hundred millions of poultry from one hundred and fifty millions of eggs, placed in a few large ovens. Should it still be urged that oxygen is indispensable to animal life, I answer, so is it to the movements of the steam engine, because by its chemical union with carbon and hydrogen in the furnace, as in the lungs, the moving principle is evolved; and, because like carbon, hydrogen and nitrogen, oxygen is an essential constituent of animal bodies.

During the passage of dark venous blood through the lungs in combination with chyle and lymph, received from the thoracic duct, its temperature is elevated, its colour changed to a bright florid hue, and its vital properties exalted. It has also been proved by the experiments of Prevost and Dumas, Denis, Le Canu, Mayer, Autenrieth and Letellier, that arterial contains a larger proportion of organic particles than venous blood; as might naturally have been inferred from the obvious fact, that during every circulation of the former through the general system, a portion of them is transferred to the solids, which are nourished at the continual expense of arterial blood. The relative proportions of fibrin contained in the arterial and venous blood of different animals, are stated by Müller, on the authority of Berthold, as follows:—

	Arterial.	Venous.
Dog	666	500
Sheep	566	465
Cat	521	474
Goat	429	366

Dr. John Davy observes, that "the use of the red particles, according to the views of Hunter, seems to be connected less with nutrition than with action, and more with the production of animal heat, than perhaps with any other function." That they do actually afford a large proportion of combustible matter before they are in a condition to nourish the tissues, is evident from the fact, that hæmatin contains a much larger ratio of carbon than albumen or fibrin; which excess of carbon unites with atmospheric oxygen in the lungs, where animal heat is evolved and imparted to the blood, carbonic acid, urea and other inorganic products formed, before they can pass out of the body in the form of excretions.

Dr. Edwards also maintains, that the temperature of animals depends greatly on the proportion of red particles in their blood, because the lower orders, in which it consists chiefly of water, are cold-blooded. But this is only one among a thousand examples that might be adduced, of the manner in which men have inverted the laws of nature, or confounded cause and effect. For as the mechanical physicians, including Boerhaave and Haller, regarded animal heat as an effect of the heart's action, motion of the blood and its friction against the solids; so did Sir H. Davy regard it as "a result of all the changes and organic actions that take place in animal bodies." And so effectually has the chemical theory of respiration been

shaken by his denial that caloric is a material agent, that Mason Good "omits the consideration of it," while he defines "respiration as the act of receiving oxygen, and throwing out carbonic acid."

In a recent course of lectures, published in the *Lancet* of 1840, by Mr. Ancell, the author maintains that animal heat results from "the molecular vital actions continually going on between the red particles and the liquor sanguinis." We are also told by Dr. Dickson, in a late work termed *Fallacies of the Faculty*, that "animal heat results from the constant mutation and motion of all the organs"—which is only another mode of expressing the opinion of Sir H. Davy, and of Bichat, who represents it as "a product of all the vital functions"—with this difference, that Dr. Dickson refers the mutation and motion of all the organs to electricity; but without explaining the origin or *modus operandi* of this mysterious agent. Alas! it is much easier to expose, than to reform, the errors of the faculty. Nor is it any definition of life to say with Sir H. Davy, that "it consists in a series of corpuscular changes"—and with Dr. Roget, that "it consists in a series of actions and reactions,"—without explaining the cause of these corpuscular changes, actions and reactions.

In regard to all the above hypotheses, I answer,—we might as well suppose that the temperature and power of steam are owing to the movements of the engine, as that animal heat depends on the action of the heart, friction, &c.; that the temperature of boiling water, and its conversion into the elastic or gaseous state, result from the vibratory or rotary motions

of its particles,—as that "animal heat results from the molecular vital actions of the blood;" that the temperature of spring, summer and winter depends on the actions which make up the movements of chemistry, geology and life—or that the caloric perpetually radiated from the sun into the planetary spaces, and again returned to the fountain from which it sprung, depends on the motions of the heavenly bodies,—as that "animal heat results from the constant motion and mutation of all the organs."*

If the vitality of the blood had not been recognized by all antiquity, and sanctioned by the universal common sense of mankind, down to the time of Harvey and Willis, it would still be evident from the well-established fact, that all the organs are formed immediately from it; and that whenever its supply is cut off, they cease to live. It is therefore clear, that all the phenomena of the animal economy, whether in health or disease, must depend on the conditions of this important fluid, which, in accordance with the doctrine of Hunter, Bordeu termed *liquid flesh*,—and that a complete knowledge of its vital properties is essential to any sound or rational system of medical theory and practice. It was justly observed by the celebrated Boyle, that "to mind the solid parts of the body, and overlook inquiry into the fluids, especially the blood, were little less improper in a physician than

* It was maintained by Anaximenes that the heat of the sun was generated by his *rapid motion*, the cause of which motion, however, was not explained. But the modern discovery, that the sun is stationary, having only a slow motion upon his axis, has encumbered this an[illegible] theory with still more serious difficulties.

it would be in a vintner to be very solicitous about the structure of his cask, and neglect the consideration of the wine contained in it." (*Essay on Human Blood.*)

One of the most important facts connected with the vital properties of the blood, is the process of coagulation by which its fibrin becomes solid, when removed from the vessels, and unites the red particles into a mass of greater or less density. But the cause of this change remains an unresolved problem. As it must always have been known that inorganic fluids become solid under the influence of cold, it was maintained by Hippocrates and Aristotle, Harvey and Sydenham, that the coagulation of blood is owing to the loss of animal heat. For the first time in the history of science, this error was refuted by Hewson, who found that the process was always retarded by cold, and hastened by increase of temperature. He therefore concluded, that it was owing to the influence of atmospheric air. But as it was observed by Spallanzani to take place within the cellular tissue when extravasated, removed from the circulation, and not exposed to the air, he inferred that it was owing to the cessation of its motion. This opinion has also been refuted by the fact, that coagulation cannot be wholly prevented by agitation of blood out of the body. Yet it would appear from the experiments of Magendie, that it is greatly retarded by the natural movements of the circulation; for, when he connected a dead tube at the temperature of the body, with the extremity of a divided artery of a living animal, the blood sent into it remained fluid while kept in motion by the heart's action.

Some have ascribed the process of coagulation to the escape of carbonic acid, and others to the loss of nervous influence, or to the death of the blood. But it is now fully established, that it is not prevented by the presence of carbonic acid, nor when placed *in vacuo*. And that it is not owing to the loss of vitality, is evident from the fact, that in the latter stages of the most malignant diseases, the blood remains fluid after death. What, then, is the rationale of coagulation? To this important query physiologists have hitherto offered no satisfactory reply; and Dr. John Davy observes, that it must still be regarded as "one of the many mysteries of nature;" that "all we know is, that from a fluid state, the fibrin becomes solid, entangling a portion of red particles and serum." (*Anat. and Physiological Researches*, vol. ii. p. 2.)

The leading facts connected with the theory of coagulation may be reduced to the following propositions:—

1. That the contractile power of the blood, when removed from the body, like that of the muscular fibres, is in proportion to the quantity of respiration, mean healthy temperature and aggregate vital energy in the different orders of animals; being greater in birds than in mammalia, and greater in the latter than in reptiles and fishes.

2. That as the temperature of arterial is higher than that of venous blood, so does the former coagulate more quickly and firmly than the latter.*

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* We also learn from the experiments of Hunter and Thackrah, that arterial resists putrefaction longer than venous blood. And Bellingeri states, that while the former is positive, the latter is in

3. That as the vital energy of animals is always diminished by reducing their temperature below the natural standard, so is the coagulation of the blood retarded by the same means, and wholly prevented by long-continued cold.*

4. That the blood of individuals belonging to the sanguine or dynamic temperament, coagulates sooner and more firmly than in such as are of a weak or phlegmatic constitution; while its contractile power is diminished by whatever impedes the function of respiration, as in phthisis, asthma, disease of the heart, the cold stage of fever, and all maladies of long standing, by which the powers of life are greatly reduced.

As a proof of the first proposition, and corresponding with the highly organized state of the blood in birds, together with its bright florid hue, we are informed by Denis, that when poured from the divided vessels of a decapitated fowl, it coagulated almost in-

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a negative state of electricity. However this may be, they are certainly *plus* and *minus* in relation to temperature, or the quantity of caloric in each, while circulating through the body.

* Sir Charles Scudamore found, that human blood which began to solidify in four minutes in air at 53°, underwent the same change in two minutes and a half at 98°, and in one minute at 120°; again, that blood which coagulated firmly in five minutes at 60°, required seventy minutes to become solid when reduced to the temperature of 40°. Nor is it true, as stated by Mr. Ancell, on the authority of Mr. Prater, that when blood is suddenly raised to 140° and 150°, its power of coagulation is destroyed; for in numerous experiments of my own, it took place rapidly in the blood of sheep at all temperatures, from 110° up to 150°, and almost instantaneously, when the cups in which it was received were placed in water at 180°, owing, doubtless, in the latter case, to solidification of its albumen, which takes place immediately at temperatures above 156°.

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one of which was placed in water at 130°, another in water at 100°, and the other exposed to the air at 51°; when they all began to coagulate in about one minute and a half, but that in the cup at 130° contracted more firmly in two minutes, than either of the others in five minutes.

Corresponding with the fact established by Hunter, that the ears of rabbits, the combs of cocks and the extremities of other animals, may be rigidly frozen, and afterwards restored to life, when gradually submitted to the influence of warmth, it has been demonstrated by the experiments of Hewson, Thackrah, Davy, Magendie and Prater that the blood of animals may be repeatedly frozen, and afterwards coagulate when thawed. Hence it is that hybernating animals, including reptiles and other cold-blooded species, after being frozen for months, as in the higher latitudes, are restored to activity by the returning power of solar warmth. The influence of caloric on the coagulating power of the blood is further illustrated by the following observations of Dr. John Davy, who found that the blood of a tropical turtle, whose temperature was 91°, coagulated firmly in about two minutes; while that of another turtle, whose temperature was 84·5°, required five minutes to become solid; and that of another, whose temperature was 58°, required thirty minutes to coagulate firmly. (*Anat. and Physiological Researches*, vol. ii. p. 10.) Mr. Marshall also found that the blood of a tortoise whose temperature was 55°, that of the room being 58°, began to coagulate in eighteen minutes, and became solid in one hour and forty-five minutes. But that when raised to the tem-

perature of 110°, (falling to 80°,) it began in nine minutes and a half, and was completed in twenty-three minutes and a half. He further observed, that when raised to 130°, it did not commence before thirteen minutes and a half had elapsed, and was completed in one hour.

It is therefore evident that, within certain limits, the coagulating power of blood is augmented by raising its temperature above, and diminished by reducing it below the natural standard. As a further proof of this, it is stated by Müller, that during winter, the blood of frogs coagulates very imperfectly. And I may add, from several observations of my own during the winter of 1840–1, that blood of the eel and several other species of fish, requires from ten to fifteen and sometimes thirty minutes to coagulate in a very imperfect manner. Let us then reject the assertion of Magendie, that "blood coagulates alike at all temperatures from 10° to 156° F." The truth is, that notwithstanding the vast number of experiments performed by this celebrated physiologist, he seems never to have inquired how far the process of coagulation is modified by the difference between warm and cold-blooded animals.*

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* Yet we are greatly indebted to him for the light which his researches have shed on the influence of various medicinal agents on the vital properties of the blood, many of which, that are constantly employed in practice, disorganize its particles, and diminish or prevent its coagulation, out of the body. For example, he has shown, that sulphuric, nitric, hydrochloric, oxalic, hydrocyanic, phosphoric, arsenious and many other acids, in small proportions, either prevent or retard its solidification,—that it is retarded by solutions of opium, belladonna, strychnia, nicotine, sulphate of mor-

That coagulation is a vital process, analogous to that by which blood is converted into the different organs, and owing to the same cause which enables the muscles to contract, was fully recognized by John Hunter, who demonstrated, by an admirable series of experiments, that when effused into healthy divided parts, it becomes penetrated with innumerable vessels that may be injected by injecting the neighbouring arteries, —causing wounds to heal by the first intention, and plugging up divided vessels.* He also maintained with Hewson, that the process of coagulation is accelerated by an increase of temperature, and retarded by cold; that the colour and coagulating power of the blood are more expressive of disease, than is any other part of the animal economy. (*Treatise on the Blood*,

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phia, digitalis, aconite, hemlock, tartarized antimony, bichloride of mercury, nitrate of copper and by nearly all the neutral salts, except in very small proportions, although most of the latter change it to a florid hue; and that while some of the above medicines precipitate the albumen of the blood, others dissolve its fibrin. Magendie has also shown, that by injecting seven grains of oxalic acid into the jugular vein of a dog, he was attacked with difficult breathing, small and frequent pulse, prostration of strength, followed by coma and death in a few hours; and that the same fatal effects were produced by injecting an ounce of the mildest neutral salts into the veins. (*Lancet* for 1839.)

* We also learn from the researches of Prevost and Dumas, that when a small quantity of blood from a living animal is immediately placed between thin pieces of talc, the red particles may be seen with a good microscope to arrange themselves in lines, or series and aggregates, that resemble chaplets of beads—a process which must be regarded as an imperfect species of organization, and as the result of its last remainder of vitality. (*Ann. des Sciences Naturelles*, tome xii.)

&c. vol. i. p. 135.) But he was wholly mistaken in supposing that coagulation is prevented in cases of sudden death from lightning, violent emotions of the mind, the more active poisons, and exhaustion from excessive muscular exertion, as has been recently proved by the accurate researches of Dr. John Davy.

At the same time, it is certain from the experiments of Hewson, that the coagulating power of the blood is diminished in all cases of congestion, intermittent fever, pneumonia, consumption, rheumatism and various other modifications of disease, by which the general forces of life are seriously impaired,—and that the process is delayed, in such cases, for ten, twenty, thirty or even ninety minutes. It is very much protracted in cases of apoplexy, epilepsy, concussion of the brain, suffocation, strangulation, violent emotions of fear and other depressing passions,* or whatever diminishes the

* It is very well known, that in cases of fright, the powers of life are remarkably diminished. That this is owing to partially suspended respiration, on which the vital properties of the blood depend, is evident from the coldness of the extremities, languor of the circulation, paleness of the skin and darkness of the blood, when drawn from a vein. In all such cases, the voluntary power of the brain is more or less impaired by the shock, and its command over the lungs so far diminished, that their chemical function is greatly interrupted, when they fail to arterialize the blood in a proper manner. Accordingly it was observed by Hewson, that whenever the pulmonary circulation is much impeded, the blood first drawn did not coagulate for ten or fifteen minutes; but that after the congestion of the weakened and overloaded capillaries was removed by taking away a few ounces of blood, it flowed from the orifice more freely, changed from a dark to a bright florid hue, and coagulated in from three to five minutes. It has also been observed by others, that blood which exhibits a bluish tint while

chemical function of the lungs, and consequently, the vital properties of the blood, or the process by which it is organized. We also learn from the researches of Denis, Le Canu and other physiologists, that in all chronic diseases, such as chlorosis, scrofula, diabetes, scurvy, diarrhœa, &c. the blood coagulates slowly and imperfectly, while in the worst forms of typhus, yellow fever, plague, malignant cholera, tetanus and hydrophobia, it scarcely coagulates at all, toward their fatal termination. And it is worthy of notice here, that during pregnancy, by which a portion of the vital energy of the mother is expended in support of the fœtus, her blood coagulates more slowly than at other periods, giving time for the red particles to subside,—thus causing the fibrin to contract by itself on the surface, and to present the appearance of a whitish crust, termed the buffy coat, which is generally witnessed in the blood drawn during nearly all cases attended with slowness of coagulation, excepting those that are marked by a great loss of vitality, and general prostration of the system.

It has been maintained by many physiologists, including Scudamore and Müller, that the relative proportion of fibrin in the blood is augmented during inflammation, and that this is the cause of the buffy coat,—an opinion which has been completely refuted by Dr. John Davy, who has shown that healthy blood

flowing, always coagulates more slowly than usual, and afterwards exhibits the buffy coat. I have further observed, that when chickens and rabbits are decapitated under the influence of fright, the blood is more dark than usual, and requires a much longer time to coagulate.

contains more fibrin than the blood in cases of inflammation. But although he admits that "very buffy blood is very slow in coagulating," and that in healthy blood the process is rapid, he maintains with Hewson, that in some cases, owing to a thinness, tenuity or liquidity of the fibrin, the red particles may subside from one-eighth to one-fourth of an inch in two minutes, and sufficiently to cause the buffy appearance. (*Anat. and Physiological Researches*, vol. ii. pp. 43–6.)

The true state of the facts is, that in all cases of protracted disease in which the chemical function of the lungs is seriously deranged, the proportion of both fibrin and red particles is more or less diminished, as proved by Denis and Le Canu, and the process of coagulation retarded; while it is equally certain, that in the early stages of acute inflammatory affections, which are marked by augmented respiration and evolution of heat, there is an increased amount of *fibrin* generated, —doubtless for the same reason that it is more abundant in the blood of birds than that of mammalia, and more so in the blood of the latter than in that of cold-blooded animals, viz., increase of temperature, circulation, &c.

In opposition to the well-established fact, that in persons of the sanguine temperament, with a broad and full chest, the blood coagulates quickly and firmly, as in all the more powerful mammalia, and still more so in birds, whose vital energy is vastly greater, *cæteris paribus*, while in persons belonging to the phlegmatic temperament, and in the various species of cold-blooded animals, the process of coagulation is imperfect,—it has been recently maintained by Mr. Ancell that

"blood coagulates most rapidly in weak animals, in weak states of the constitution, and in diseases of debility"—that "when the blood is a long time in coagulating, its contractile power is strong, corresponding with the vigour of the constitution." (*Lectures on the Blood, Lancet*, Jan. 1840.)

This extraordinary statement, so inconsistent with the analogies of nature, and which the intelligent author has offered as a general axiom, seems to have been founded on the observations of Hewson, Dr. Davy and others, that the blood of animals exhausted by excessive hemorrhage, and by long-continued muscular exertion, coagulates much sooner than when taken from the vessels in a healthy state. In regard to the cause of this apparent exception to the general laws of physiology, no adequate explanation has been offered. All parties agree, that it is a beautiful provision of nature to arrest hemorrhage, by plugging up divided vessels. When it was proved by the analyses of Prevost, Dumas, Magendie, Denis and Le Canu, that the proportion of fibrin is always diminished by loss of blood, the rapidity of its coagulation was referred by some to an excess of serum, or of saline matter. But we have seen that in cases of protracted disease, the serous portion of the blood is augmented in relation to the quantity of fibrin and red particles, while its coagulation is both slower and weaker than in health.

The fact is, that although the blood of an animal exhausted by over-exertion, like the last running of blood in cases of excessive hemorrhage, coagulates almost instantaneously, the crassamentum is always

loose and infirm. There is reason to believe, that the rapidity of the process is owing partly to diminished motion and vitality of the blood; and that, like the rigidity of the muscles after death, it depends on the last remains of contractility, as will appear from the following facts. In the first place, it is well known, that when blood is extravasated, and its motion arrested, as in uterine hemorrhage, and in cases of ecchymosis, it very soon coagulates, although surrounded with living parts; while it is equally certain, that the action of the heart and general activity of the circulation, are greatly diminished by loss of blood. Secondly, it is well known to butchers, that in animals exhausted by over-exertion, rigidity of the muscles comes on *much* sooner after death, and their blood coagulates *much* more rapidly, than if slaughtered in vigorous health. I have also observed that in a sheep which had been exhausted by travelling to market, the extremities were cold, the circulation exceedingly languid, and the muscles stiff, even *before death.* In accordance with this fact, I found that when an ounce of its blood was received from the divided vessels of the neck, it became solid in half a minute. It is therefore probable, that when the motion and vitality of the blood are thus diminished, *the process of coagulation may actually commence, though imperceptibly, before it leaves the vessels;* (just as water begins to congeal insensibly at 39°, but does not become solid till reduced to 32°;) *and for the same reason that the muscles become stiff before death.*

It is stated by Richerand and Orfila, that in cases of sudden death while in the full vigour of health,

caused by suffocation in the mephitic gases, the temperature and flexibility of the muscles remain for several hours after death. And it is certain, that whatever may be the cause of the *roideur cadavérique*,—whether mechanical, chemical or vital—and whether it be owing to coagulation of the blood, as supposed by Orfila, Beclard and Treviranus—the contractility of the muscles continues only so long as their temperature remains above that of the surrounding medium, and wholly ceases whenever the body becomes cold,—for if the limbs be then flexed, they do not again become rigid. Bichat asserts, that after death, the cessation of absorption is simultaneous with the subsidence of animal temperature. And Magendie says, that it goes on for a considerable time (two hours) after death. Müller relates on the authority of Nysten and Sommer, that rigidity begins in fifteen or twenty minutes after death from lingering maladies, in which the powers of life have been greatly exhausted—that it commences sooner in infants and very old people than in robust constitutions, or in such as have been carried off by violence in the full vigour of health, without loss of blood,—in which it does not come on for several hours after the circulation has ceased, and remains for a proportionably longer time. It has been also said, that after death from exposure to intense cold, (in which the rigidity commences *before* death,) it is completed very soon afterwards—and that in a case of tetanus, the spasmodic contractions passed immediately into the rigidity of death. But that it consists of the last remainder of vitality, is evident from the fact, that it always disappears before putrefaction

begins, and its duration is shortened by whatever diminishes the previous forces of life.

In accordance with the opinion of many modern physiologists, Cuvier represents the process of nutrition, by which blood is converted into the different organs, as the greatest mystery of life. And Sir Charles Morgan observes, that "the conversion of arterial blood into venous blood is a process involved in the deepest obscurity"—that "whether any single element is abstracted, where the change takes place, or whether the alteration depends upon a change of disposition in all the elements among themselves, cannot even be guessed." (*Philosophy of Life*, p. 145.)

But we have already seen, that during the passage of dark venous blood through the lungs, in combination with chyle and lymph, variable proportions of carbon and hydrogen are given off, and unite with atmospheric oxygen, in exchange for which caloric is received, with more or less nitrogen, according as the aliment contains more or less of that element,—that during the transition of blood through the pulmonary tissue, its temperature is elevated from 1° to 3°, its colour changed to a bright florid hue,* its specific

* Hippocrates seems to have been fully aware, that the temperature is higher in the left ventricle of the heart and aorta, than in the right ventricle or vena cava. He also observes, that the heart is the well-known fountain of the aorta, which is connected with the lungs by the trachea, which he regarded as the upper extremity of the aorta. (*περι Φλεβων*, i. ii.—*περι* Αρχων, vi.—*περι* Καρδιης, vii. viii.) But so little did this greatest of the ancient physicians know in regard to the true theory of respiration and sanguification, that he speaks of the former as a cooling process; while he referred the dark or livid colour of what we call venous blood, to

gravity diminished, the proportion of its organic particles augmented, and all its vital properties exalted. In this state, it excites the left ventricle of the heart to contract, by which it is impelled into the ultimate

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the contraction of the heart, and the rubicund or florid hue of what is now called arterial blood, to its dilatation. And so little did he know in regard to the office of the brain, that he represents the mind (γνωμη) of man as seated in the left ventricle of the heart. But as Pythagoras, Anaxagoras, Democritus and Heraclitus, regarded the brain as the organ of mind, it may well be doubted whether Hippocrates was the real author of the treatise ascribed to him, on the heart. Galen also observes in his treatise on the use of the pulse, that on opening the ventricles of the heart of an animal, *especially the left one*, if the finger is immediately introduced, *the heat is then felt to be greater*, and *continues longer, than in other parts—Page* 870. (*Cox's Epitome of Hippocrates and Galen*, page 536.) He further states, in his *Finitiones Medicæ*, when explaining the difference between a vein and an artery, that the latter contains less blood, (which is more attenuated,) but *more spirit*, is *more warm*, and endowed with a pulsating motion. (*Cox's Inquiry into the Claims of Harvey*, page 124.) It is therefore evident, that without the aid of thermometers, the ancients had discovered the important fact that arterial is warmer than venous blood. But although he speaks of respiration as essential to life, and superior in the importance of its function to the stomach, or even the brain, he seems to have had but vague, erroneous and contradictory views on the subject; for at one time he represents its object to be the conservation of the innate heat of the blood, while at another time he describes the air inspired as intended to ventilate and cool the blood. In his treatise on the doctrines of Hippocrates and Plato, he represents the liver as the organ of sanguification, and the origin of the veins. (COX, *op. cit.* page 541.) It is therefore manifest, that his physiology of respiration and sanguification was not much better than his knowledge of anatomy. As for Aristotle, he maintained that the blood is warmer in the right ventricle of the heart than in the left. (LE CLERC, *page* 271.)

tissues of the whole body, where the caloric just received in the lungs, together with a portion of arterial blood, percolate the delicate coats of the capillaries, unite with the solids by vital affinity, and form the various secretions by glandular action.

As proofs of what has just been stated, the temperature, vital activity and renovation of all the organs, are constantly maintained at the expense of arterial blood, during its conversion into the venous state, while passing through the systemic capillaries, where its temperature is reduced, the number of its organic particles diminished, and its power of sustaining the healthy state of the different functions is greatly impaired,—when it returns to the lungs for a fresh supply of organic particles and of living fire. If the temperature of the blood were not raised above that of the solids while passing through the lungs, there could be no transition of caloric from one to the other —no combination of its proximate constituents with the membraneous, bony, muscular and nervous tissues. Nor could chyle and venous blood be converted into the arterial state, without giving off carbon and hydrogen in the lungs, by which caloric is evolved, the temperature of the blood elevated and its composition renewed.*

* It is therefore not true, as maintained by Dr. John Davy, that "the object of respiration is to introduce oxygen into the blood, and separate carbonic acid from the blood"—that "animal heat is owing to the fixation of oxygen in the blood in the lungs, and to the combinations into which it enters in the circulation, in connection with the different secretions and changes essential to animal life." For if it be a fact, which *he* has clearly demonstrated, that the temperature of blood is elevated while passing

Should it be urged, that arterial contains more oxygen than venous blood, I reply that the difference is very small, and wholly disappears in the lungs, on giving off carbon and hydrogen, where venous becomes arterial blood,—that although it be true that the latter has been found to contain a little more oxygen, and the former a little more carbonic acid, as observed by Magnus, those gases exist in a state of merely mechanical mixture, and not as organic constituents of the blood. Besides, it has been shown by the microscopic observations of Müller and others, that the form and magnitude of the red particles are the same in arterial as in venous blood. Nor has there ever been the slightest proof that oxygen causes arterial blood to unite with the solids while passing through the systemic capillaries,—nor that carbonic acid is there received, as it changes to the venous state. We are then bound to conclude that the difference between arterial and venous blood is owing chiefly to the greater amount of caloric and organic matter in the former. It has also been shown in a preceding chapter, (*page* 502,) that when the blood of

through the lungs, and diminished while passing through the general system, animal heat must be evolved in the pulmonary air-cells, where the carbonic acid is generated, and there unite with the blood, from which it is given off to the different organs. Nor is it true, as maintained by Dr. Stevens, that arterial blood is changed to the venous state, by acquiring carbonic acid in the systemic capillaries, and again arterialized by the attraction of atmospheric oxygen for carbonic acid, and the abstraction of the latter in the lungs,—much less, that arterial blood owes its colour and vital properties to the salts contained in the serum; because they exist in chyme and chyle, which are white.

a living artery is confined between two ligatures, or in glass tubes hermetically sealed, it assumes all the properties of venous blood, without the loss of anything except caloric. Moreover, it is manifest, that if the composition of the solids be renewed, and their temperature maintained, at the expense of arterial blood, while the latter is changed to the venous state,* and deprived of its nutritive properties, there is no conceivable method of explaining the transmutation of one into the other, without admitting, that *nutrition consists in the transfer of vital heat and organic particles from arterial blood to the solids.*

The principal mystery connected with the process of nutrition, is the law of elective affinity by which the proximate constituents of the blood unite with the respective tissues. Some light is thrown on this problem by the fact that the bud of one fruit when grafted on the tree of another, retains its original specific character; showing that the sap of the tree into which it was inserted, is changed on coming into contact with the graft. And so of morbid animal growths. This

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* Physiologists have often asserted, that the paralyzing influence of venous blood when sent to the brain, stomach and other organs, is owing to some poisonous property which it acquires while circulating through the capillaries. But that its fatal influence is merely negative, owing chiefly to the loss of vital heat in the ultimate tissues, and not to any positively noxious influence, would appear from some experiments of Dr. Kay, (recorded in the 28th vol. of the *Med. and Surg. Journal,*) who found that after a limb had been paralyzed by depriving it of arterial blood, its contractility was partially restored by the influx of fresh venous blood,—which was doubtless owing to the fact, that fresh venous blood contains more caloric than the solids, even at the same temperature.

much, however, is certain, that if the temperature of the blood be not raised above that of the solids, there could be no transition of caloric from one to the other, —no combination of fibrin with the muscles,—of albumen, oily, phosphuretted and other matter, with the brain and nerves,—of albumen with the membranes, ligaments and cartilages,—nor of lime with the bony textures. The proof of which is, that after the temperature of arterial blood has been reduced to an equilibrium with the solids, and its properties changed to the venous state, it fails to nourish the brain, nerves, muscles and other tissues,—to maintain their temperature and specific modes of action, and to elaborate the various secretions. The inference is therefore obvious, that animal heat is the agent by which these vital affinities are produced and the activity of the various tissues maintained. Nor is this any more remarkable, than that the chemical union of water with the aromatic constituents of tea, coffee and many other bodies, including the various salts, should be owing to the transition of caloric from one to the other. Nor is it more strange, that the caloric disengaged in the lungs during respiration, should there convert chyle into blood, than that the same active principle should cause oxygen and hydrogen to unite in the formation of water, or that solar caloric should determine all the chemical and vital transformations of the vegetable world.

Moreover, that animal heat is the *cause*, and not the effect of secretion, as maintained by Philip and many others, would appear from the following undeniable facts:—1. That the secretion of perspiration is

much more copious during summer than winter, and in tropical than in the higher latitudes; while it is known to be greatly augmented by the high artificial temperature of glass-works, foundries, &c.;* and that sweating is the natural termination of the hot stage of fever. 2. That in cows, goats and other domestic animals the secretion of milk is more abundant during summer than winter, especially in cold climates, and that the growth of all young animals is greatly retarded by cold weather, unless they be protected by suitable shelter. 3. That the menstrual secretion, like that of the skin, is checked by exposure to cold damp air, getting the feet wet, by wearing too thin garments, and by whatever causes the abstraction† of vital heat from the system more rapidly than it is obtained by respiration; or whenever the latter process is dimi-

* Dr. Southwood Smith found, that workmen who are exposed to the intense heat of the London gas-works, lose from two to five pounds of perspiration in the space of one hour, twice a day, making the aggregate from four to ten pounds,—during which they consume enormous quantities of malt liquors. (*Philosophy of Health*, vol. ii. p. 396.)

† The menstrual secretion also diminishes from the tropical regions, where it amounts to twenty-four ounces, more or less, to the warm climate of Greece, where, according to Hippocrates, the average is twenty ounces; whereas in the middle latitudes of Europe and America it does not exceed six or eight ounces, and not above three or four in the polar regions. As might be inferred from this difference, the women are said to be more voluptuous in warm than in temperate, and least so in frozen climates, where sensibility is at zero. Hippocrates observes, that among the Scythian women, the menses flow but rarely, in small amount, and that they are not fruitful; while the wild animals are small and few in number. (*On Airs, Waters and Places.*)

nished by the depressing emotions of grief, fear and anxiety, which are attended with cold extremities, languid circulation and a general loss of vital energy. 4. That as the quantity of secretion throughout the vegetable world is always in proportion to the heating influence of the sun, and wholly arrested during winter,—so are all the secretions of animals during health, in proportion to the amount of caloric they derive from the atmosphere by respiration, and wholly arrested or greatly diminished whenever the temperature of the body is reduced much below the normal standard by immersion in cold water, or during the cold stage of fever, cholera, &c. 5. That if the temperature of blood be not raised above that of the solids, it cannot excite the stomach to secrete gastric juice, nor any of the other glands their respective fluids.

Again, that neither secretion nor nutrition depend on nervous influence, is evident from the fact, that the germs of all animals are generated by secretion, and developed by nutrition, before any part of the nervous system is formed, as stated in the preceding chapter, *page* 538. Yet we are informed by Dr. Roget, in an article on Animal Physiology, contained in the *Library of Useful Knowledge*, p. 92, that "the nervous system exerts a certain action upon the blood, by which are maintained the secreting and other assimilating processes, a disengagement of caloric produced and the temperature necessary to animal health sustained." He also adds in his elaborate *Bridgewater Treatise*, that "not only muscular contraction, but the organic affinities which produce secretion, and all those

unknown causes which effect nutrition, development and growth of each part, are placed under the control of the nervous power." (Vol. ii. p. 357.)

Similar views have been offered by Tiedemann, who observes, that "perhaps an imponderable fluid, resembling galvanic electricity, is generated in the nerves, which causes changes in the blood, passes through the delicate net-work of the glands, and renders them capable of secreting, as supposed by Wollaston, Berzelius, Brodie, Philip and others." (*Comparative Physiology*, p. 207.)* And so far has Dr. Southwood Smith been fettered by this obscure hypothesis, that in his excellent work on the *Philosophy of Health*, he represents "the repulsive power of the blood on which its fluidity depends, as a vital endowment, derived, *probably*, from the organic nerves, so abundantly distributed to the coats of the blood-vessels;" while in another place he maintains that "secretion is effected by means of the electric fluid, conveyed to the different organs by the ganglionic nerves."† And although he admits that the temperature of arterial is somewhat higher than that of venous blood, he observes that the difference is so slight, that in the general theory of animal heat it may be disregarded. (Vol. i. p. 347; vol. ii. pp. 147, 213, 326.)

* As to M. Matteucci, he maintains that "the nervous fluid is not caloric nor electricity, but that it is produced by the chemical action of nutrition." (*Comptes Rendus*, March 15, 1847.)

† In a late work by Rudolph Wagner, he observes, that "the final cause of the secretion of gastric juice lies in the nature of the animal organism, and is unknown to us." (*Elements of Physiology*, part ii. p. 346.)

Is it then possible that physiologists are in doubt whether the fluidity of the blood is owing to the same cause which determines the fluidity of the ocean? Or is it possible that the Author of Nature would have ordained that the temperature of arterial should be higher than that of venous blood, if the difference were not essential to the well-being of the animal economy? *The truth is, that this "slight difference" constitutes one of the most important facts connected with the whole theory of physiology, pathology and therapeutics.* In accordance with the views of the ancients, who believed with Homer, that "strength is derived from spirits and from blood,"—it is now completely established, that the contractile power of the muscles, whether voluntary or involuntary, is directly in proportion to the quantity of arterial blood with which they are supplied, and the rapidity of its circulation through them. *But that caloric is the spirit on which its power of maintaining their nutrition and strength depends, is manifest from the facts already stated, that if the temperature of the blood be not raised above that of the solids, while passing through the lungs where it is formed, it cannot unite with their substance;* and that whenever the general system is reduced below the natural standard by the abstraction of its vital heat, or by a deficient supply of it by respiration, all the energies of the animal machine are proportionally diminished.

On the other hand, whenever the temperature of the living body is raised much above the natural standard by the external action of caloric, so that the solids are brought nearly to an equilibrium with that

of the arterial blood, the operations of secretion and nutrition are nearly suspended, and all the energies of life proportionally diminished. The reason of which is, that under such circumstances, there is very little caloric transferred to the solids in combination with the blood, which, therefore, returns to the right side of the heart, of nearly the same temperature, florid hue and quantity of organic particles, as when it left the lungs. Hence it is, that when the system is raised above the natural standard, as during immersion in the hot bath, or surrounded by an atmosphere from five to ten or more degrees above the healthy temperature of the body, as in the tropical portions of Africa, India, New Holland and South America during the heat of the day,—all the powers of mind and body are prostrated, attended with syncope, apoplexy, and frequently death, if not relieved by cooling ablutions by which the system is reduced to its natural *plus* and *minus* condition of arterial blood and of the solids. For it is a certain fact, that without this essential condition, none of the vital functions could be long carried on.

The dynamical agency of caloric is not more essential to the movements of a steam engine than to the muscular power of animals and the activity of all their functions. In both cases, it is obtained by the combustion of carbon and hydrogen. In the former, it is evolved in the furnace, communicated to the boiler, where it unites with water, and converts it into an elastic gas, which, by acting on the piston, sets all parts of the machine in motion,—whereas in the latter, it is disengaged in the lungs, where it con-

verts chyle and lymph into the proximate constituents of blood, and raises its temperature, by which the heart is excited to contract, and send the vital stream to all parts of the animal system. And as the power of steam to move the piston is destroyed on parting with its caloric in the condenser, so is that of arterial blood to maintain the action of the heart, stomach, brain and voluntary muscles diminished or destroyed by parting with the caloric it receives in the lungs, while passing through the ultimate tissues of the body, which cannot be nourished and vitalized by dark venous blood,—for the simple reason, that its temperature has been reduced to an equilibrium with that of the solids, and its vital properties impaired, until again renovated by respiration.

Thus it is manifest, that when stripped of all hypotheses, and reduced to its utmost simplification, the science of animal physiology may be reduced to a very small compass,—that a difference between the temperature of arterial blood and that of the solids is absolutely essential to all the phenomena of life,—that the transformation of blood into the different organs depends on the same attraction of fluids for solids that determines the growth of plants, and the capillary circulation in animals that have no heart, like that of the lacteal and lymphatic absorbents. But why should I waste time in maintaining a doctrine that requires only to be once fairly stated, to give it the force of a self-evident truth? I answer, that such is the influence of "stone-blind custom," in obscuring the perceptions of mankind, that they generally disregard the plainest facts, when not in accordance with established sys-

tems, however unsatisfactory the latter may be,—that it is therefore often necessary to insist upon the clearest propositions,—to add "line upon line, and precept upon precept," until the light of common sense shall penetrate the thickest crust of prejudice, and dispel the mists of error that have so long dimmed our intellectual vision. But what shall we say of men who wilfully close their eyes to the azure heaven, the shining sun and the growing corn? who "grope in the noon-day as in the night," and dig their way in the dark like a mole, until they lose the power of vision? Alas! this is their condemnation, that light has come into the world, and they reject its revelations.

The finest specimen of mechanism ever yet devised by the skill of man is the steam engine, which is destined to augment the power of producing wealth and happiness an hundredfold. But as the grandest inventions of human genius are only feeble imitations of nature, (which Plato beautifully termed *the art of God*,) the process of living combustion is absolutely perfect, and the power thus obtained, applied with the admirable wisdom and efficiency that characterize all the operations of the Divine Architect. For, in addition to the large amount of caloric that is wasted by imperfect combustion in the furnace of a steam engine, including what is lost by radiation, or passes off with smoke, there is a great loss of power, owing to its being applied only to the piston; whereas, in the animal machine during health, and where the climate is temperate, there is no waste of caloric, which is conveyed and applied directly to every part of the body, in combination with arterial blood, by which

the composition and vitality of all the organs are renewed, while they are endowed with the faculties of motion, sensation and the exalted attributes of intelligence.

As an example of the difference between the dynamical effects of ordinary combustion and that of the living frame, we are informed by Mr. Thomas Wickstead, that during the consumption of one hundred pounds of small Newcastle coal, in the furnace of the best Cornish steam engine, a power is generated equal to the elevation of from 82,000,000 to 113,500,000 pounds a foot high, making an average of above 97,500,000 pounds, or nearly double that of Watt's engine with the same amount of coal. But according to the mean result of experiments performed by Emmerson, Desaguliers, Bolton and Watt, Smeaton, Bevan, Wood, Tredgold and Leslie, as reported in the *Journal of the Franklin Institute*, the tractive power of a first-rate English dray-horse is equal to the elevation of 16,500,000 pounds a foot high in eight hours, when fully exerted. Yet a horse, living on twelve pounds of farinaceous food per day, cannot consume above six pounds of carbon and hydrogen by respiration in twenty-four hours, and perhaps about three pounds during eight hours vigorous exercise. From which it follows, (if these data be an approximation to the truth,) that thirty-three such horses would consume about one hundred pounds of carbon and hydrogen by respiration in eight hours; and that they would generate an aggregate force equal to the elevation of 550,000,000 pounds a foot high, or above five times that which is created by the combustion of one hun-

dred pounds of coal in the furnace of a Cornish engine.*

It has been also ascertained by experiments in England, that a man working on a treadmill for eight hours, will elevate 1,500,000 pounds one foot high, and that a Cornish steam engine will perform the same work by the expenditure of one and a half pounds of coal. If, then, we suppose that by such exercise the respiration of man is doubled beyond the average, he would expend about six ounces of carbon and hydrogen in eight hours; from which it follows, that the same amount of combustion in the living body will generate about four times as much power as a steam engine.

In every description of mechanism, the power generated is always directly in proportion to the quantity of the impelling agent, cæteris paribus. As the velocity of a steam car depends on the amount of caloric communicated from the furnace to a given quantity of water in the boiler, and thence to the piston, so is the locomotive power of animals determined by the amount

* Since the first edition of this work was printed, many experiments have been performed in Germany, France and other parts of Europe, from which it appears, that an average-sized horse consumes about 6·40 times more oxygen than a man; or, in the ratio of 6504 to 1015 grammes in twenty-four hours. Dumas has also calculated, that from 1000 to 1200 grammes of carbon would be burned in a steam engine while carrying a man from the level of the sea to the summit of Mont Blanc; whereas a man would make the ascent on foot in two days, by consuming 300 grammes of carbon. (See *Matteucci on the Physical Phenomena of Living Beings*, pp. 152, 325; London ed., 1847.)

of the same active principle imparted to blood in the lungs, and thence to every part of the body. Nor is this any more remarkable, than that the velocity of planets through their orbits, like all the changes and transmutations which make up the history of chemistry and geology, should be directly in proportion to the heating influence of the sun.

But as it is an universal law of nature, that the cause of force is always expended in producing motion, the caloric which is employed in uniting the proximate constituents of blood with the different organs, and in maintaining their healthy activity, is carried off and removed from the system,* with a rapidity corresponding with the energy of the brain, muscles, stomach, &c. until the vital affinities by which the molecules of

* The caloric conveyed to the different glands in combination with arterial blood, and in elaborating the various secretions, is also expended by their action, when it passes out of the body with the exhalations from the skin, lungs and kidneys, or from the surface by radiation. Were it not for this rapid expenditure of blood and vital heat, the temperature of birds would be far higher than it is, and their blood proportionally richer in organic particles; for we have seen that they consume at least double the ratio of oxygen and of aliment as the same weight of mammalia. But as the functions of circulation, secretion, nutrition and muscular motion are more energetic in birds, their blood and animal heat are transferred to the solids, and expended in maintaining the renewal of their composition and vital force with such rapidity, that their mean temperature, and the ratio of organic particles in their blood, are not much higher than in mammalia. For the same reason, the temperature of a man with large thorax and sound lungs, does not much exceed that of one with a narrow chest, diseased lungs and imperfect respiration,—because in the former it is more rapidly expended by secretion, nutrition, sensation and locomotion.

arterial blood are transferred to, and kept in a state of combination with, the solids, is gradually diminished, and finally dissolved—when, having performed the office of renewing the structure and vitality of the different tissues, they successively fall from their places, and are taken up by the lymphatic absorbents, which convey them into the general circulation as worn-out materials, to be again renovated in the lungs, and finally removed from the system by the several emunctories; while their places are immediately taken by fresh organic particles that are continually supplied from the living fountain of arterial blood.

Thus we perceive, that the vital energy of the brain, nerves, stomach, muscles and all other parts of the body, is maintained by the successive additions of new matter, which no sooner unites with the different tissues, than it begins to die;—that when the caloric by which the particles of arterial blood are united with the solids, is expended by their action, their vital attraction begins to diminish;—that no healthy individual preserves his absolute identity for a single moment;—that every part of the body is in a state of perpetual motion, and transition from life to death, of organization and disorganization, renovation and dissolution;—that whenever the worn-out particles are not replaced by new and living ones, emaciation ensues, and all the powers of life decay;—in short, that whenever the process of nutrition is arrested, death speedily closes the scene.

It has been repeated an hundred times by different physiologists, that the affinities of life are superior to

those of dead matter.* That this is actually the case, would appear from the rapidity with which birds and mammalia convert the constituents of dead matter into blood and their respective tissues; and from the fact, that a strong man has been known to lift about ten times his own weight from the ground, in opposition to the force of gravity,—while the cohesion or contractility of a living muscle is about ten times that of a dead one, *cæteris paribus*.† But I have shown that

* It is also maintained by nearly all physiologists, that the cause of vital action is different from that of chemical affinity, cohesion, &c. because we cannot combine the elements of oxygen, hydrogen, carbon and nitrogen, so as to form the proximate constituents of organized bodies. But Liebig informs us, in his late excellent work on the *Application of Organic Chemistry to Agriculture*, that urea, allantoin, formic acid and oxalic acid, which are products of vital action, have been formed out of the body by chemical action. I have shown, however, that the principal difference between the operations of ordinary chemistry and those of life is, that the latter are more complex. They are also more energetic and exalted in animals than in plants, because in the former the organizing principle is continually renewed. The truth is, that we cannot combine the elements of oxygen and hydrogen together, so as to form water, any more than we can form blood, or any other organized substance, but only bring the materials of which they are composed together, while nature performs the rest.

† The manner in which the contractile power of a muscle is maintained by the perpetual influx of arterial blood, and diminished by cutting off the supply, may be partially illustrated by the mechanical process of moistening a dry rope with water, which causes it to contract with such force as to raise an immense weight from the ground, until the water is expended, when the weight descends. The reason of which is, that the particles of the rope have a stronger attraction for those of water than for each other without the intervention of a liquid. And such is the vast force with which water

this power depends on the rapidity with which the composition of the part is renewed by fresh arterial blood, and is in proportion to the amount of caloric that passes through it from the lungs in a given time. For example, it is because more caloric is received from the atmosphere, and more blood generated in the lungs, of warm than of cold-blooded animals, that the composition of the former is renewed more rapidly, their organization more highly developed, their powers of resisting the ordinary forces of affinity much greater; and it is because the nutritive process is more rapid in birds than in mammalia, that the muscular power of the former so greatly exceeds that of the latter.

So long as any part of the body is supplied with good arterial blood, and with a copious flow of animal heat, by which its particles are united with the solids, and kept in a state of perpetual motion, chemical decomposition is prevented. Nor can the blood undergo coagulation while in this state of motion and perpetual renovation. But whenever the process of nutrition is greatly diminished, as in scurvy, typhus, yellow fever and other malignant diseases termed putrid, chemical

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combines with dry wood, that by introducing dry wedges into the crevices of huge rocks, and keeping them moist, these may be readily split open. Humboldt, Cuvier and some other physiologists, have maintained, that muscular contractility is generated by the perpetual coagulation of fibrin. And it must be confessed, that this explanation is a very near approximation to the truth; for it certainly does depend on the union of fibrin with the muscular tissue, during which it becomes solid, as in the process of coagulation. But they seem not to have had the slightest suspicion that caloric is the cause of both coagulation and nutrition; nor that the cohesive power of all the organs is diminished by its expenditure.

action commences, even before the entire extinction of vitality.* If then it be true, that *the vital force of animals in health, and their power of resisting the laws of dead matter, be in proportion to the quantity of caloric that unites with their tissues*, what shall we say of those physiologists who have written so many works on medical science, without even attempting to explain the office of heat in the economy of life, or what the blood receives while passing through the lungs, and what it loses while circulating through the ultimate tissues of the body?

The wonderful activity and flow of spirits that characterize the period of youth, are owing to the rapidity of nutrition and growth. Like birds, children are in a state of perpetual motion during health; and notwithstanding the smallness of their locomotive organs, many of them will run for hours without exhaustion. For the same reason, the power of resisting the vari-

* The extravasations of blood that take place during scurvy, the latter stages of typhus and other malignant diseases, including the serous portion of the blood effused in dropsy, and which forms the rice-water discharges of cholera, are owing to the broken-down condition of the solids, and diminished cohesion of the capillary vessels, at a time when the nutritive process is nearly suspended. The cold sweats that precede death are owing to the same cause. But Galen explains them by saying, that the innate heat is nearly overpowered by the humours which engender the disease. *The effusion of blood and serum into the ventricles of the brain in many cases of apoplexy is not the cause, but an effect of weakened cohesion of the vessels, which also constitutes the hemorrhagic and dropsical diatheses.* In cases of *chronic inflammation* of the brain and other organs, their texture becomes softened in proportion as the nutritive process is diminished.

ous causes of disease is greater during youth than at any other period of life; for it has been ascertained, that from the fifth to the sixteenth year, fewer deaths occur in England than at any other age. But after the completion of growth, or when nutrition and absorption become equal, all the functions of life are performed with less rapidity, while fatigue is much sooner induced by muscular exertion. And as old age comes on, the lungs diminish in volume, respiration, sanguification, circulation, secretion, nutrition and all the operations of life become languid, the extremities cold, the skin dry and harsh, the hair gray or white, the muscles stiff, the eyes dim, the mind feeble, and "man hastens to his long home."*

In the theory of nutrition is to be sought the proximate cause of all diseases, from the simplest state of inflammation to general fever, consumption, dropsy, tetanus and other spasmodic affections. For if the blood be the fountain of life, from which all the organs are immediately formed, it follows, that whatever impairs its natural properties, must derange the nutritive process by which the healthy condition of the body is maintained. Nor is it possible that disease of the stomach,

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* In a fragment preserved by Philo, and ascribed to Hippocrates, the life of man is divided into seven ages; the first of which includes the period of *infancy*, from birth to the end of seven years; the second, or that of *boyhood*, extends to the fourteenth year; that of *adolescence* to the twenty-first year; that of *youth* till twenty-eight, or full development of the whole body; that of *perfect manhood* until forty-nine; that of *seniority* until fifty-six, when old age commences. (*Opera Hippocratis*, vol. i. p. 315. Vander Linden edition.)

brain or any other organ, could exist for any length of time, while supplied with an abundance of good arterial blood; for if the latter be sound and healthy, so must be its products.

But if its natural condition be so far deranged, that its power of uniting with the solids, and of maintaining the various secretions, is seriously diminished, a portion of the caloric obtained by respiration, that is transferred to the solids during health, and expended in carrying on the various functions, is given out in the free state, or rather accumulates in the blood, causing a preternatural elevation of temperature, and loss of power in the general system. In other words, so long as the balmy vital heat received in the lungs is employed in combining the proximate constituents of blood with the solids, and in elaborating the various secretions, the temperature of the body remains at the natural standard; all the functions are performed with healthful regularity, and there is no preternatural or morbid accumulation of heat.* *Here then is a key to*

* Similar effects may be traced in the phenomena of nature on a grand scale. For example, so long as the caloric received from the sun is employed in combining with water, and converting it into vapour, which is carried off to colder regions by winds, the atmosphere is kept at a moderate temperature, even during summer. But when the atmosphere is saturated with vapour, and its circulation ceases, as during the calm that precedes a thunderstorm, *the earth becomes feverish,* (from an accumulation of caloric, which is no longer carried off in the combined state,) and oppressively sultry over large sandy plains, where there is no water. Besides, a large proportion of caloric is employed in the operations of universal chemistry, and the growth of plants, without which it would accumulate in the atmosphere in the free state, and render it oppressively warm.

the whole theory of fever, which depends essentially on a diminution and derangement of the formative process, as shown by the rapid emaciation that takes place during its progress, and which always terminates on the restoration of secretion and nutrition.

The truth is, that all constitutional diseases are owing to some alteration of the blood, and derangement of its vital properties, which are impaired by whatever seriously diminishes the functions of respiration, secretion and nutrition. If the capillaries of the lungs be paralyzed by the inspiration of cold air, less carbon and hydrogen than usual are given off, less animal heat evolved, the temperature of the blood is reduced, its due arterialization prevented, its healthy properties so far deranged, as to diminish its power of uniting with the solids, and of maintaining the various secretions. The consequence of which is, a congestion of blood in the lungs; and if the latter state remain for any length of time, there is a stagnation throughout the systemic capillaries, so long as the chill continues. During this state, the transition of caloric from blood to the solids is greatly diminished. But as the function of respiration, though greatly impaired, still continues to go on, the caloric thus evolved and imparted to the blood, gradually raises its temperature above the natural standard, by which the action of the heart is augmented, until the obstruction in the systemic capillaries is overcome, and the superfluous caloric is transferred to the solids, or carried off by the different emunctories, when the fever subsides.

If the blood be not constantly depurated by the elimination of sweat, urine and other excrementitious

matters, its vital properties are impaired, and the springs of life vitiated at the fountain head. For example, if there be three pounds of water exhaled from the skin every twenty-four hours, and perspiration be checked by exposure to cold, the chemical and vital character of the blood must be more or less changed, unless prevented by a copious flow of urine. Or if the amount of carbon and hydrogen exhaled from the lungs be greatly diminished, as during the cold stage of all maladies, the blood is no longer renovated as in health, but becomes grumous and dark coloured, and loses the power of uniting with the various tissues. It has also been found, that when the kidneys are extirpated, the animal is seized with difficult respiration, shivering, fever, vomiting, purging, typhoid symptoms, coma, and dies in from ten to thirty hours, or a few days at most; urea is found in the blood after death. (*Müller's Elements*, p. 151.)

What then must be the result when nearly all the worn-out or effete matter of the body, including the poisonous drugs so often introduced into it by physicians, are retained in the blood, as when the excretions are arrested? Has anything noxious been absorbed into the blood through the lungs or from the stomach? It must be carried off by the emunctories before health can be restored.* Nor is it possible to overcome any derangement of the solids, and bring the system back to its healthy state, without following the indications

* I once saw a well-marked fever produced in a healthy child, six years old, by a teaspoonful of hive syrup, which was intended to prevent a threatened attack of croup. The fever followed in half an hour after the medicine was taken.

of nature by restoring the action of the emunctories, and thus improving the vital properties of the blood. Whenever circulation and nutrition are greatly diminished in any part of the body, its texture is very soon removed by the absorbents, causing an ulcer or abscess, which can be restored only by the formative process, or by the deposition of new matter termed granulations, that fill up the cavity. Has a bone been broken or attacked with necrosis? It can be united, and the loss repaired, only by the nutritive process. Or has the whole body been wasted by disease to a mere skeleton? It can be restored to its natural and healthy condition only by the same process.

The celebrated *vis conservatrix naturæ of Stahl, Gaubius, Mead, Cullen and many other authors, is only a general term designating the natural action of all the organs; and is in proportion to the amount of respiration, sanguification, secretion and nutrition.* Hence it is, that a broken bone unites much sooner in birds than in mammalia,—sooner in youth and adolescence than in old age, and always sooner in persons of large chest and sanguine temperament, than in such as have a small thorax, imperfect lungs or feeble and phlegmatic constitutions. But whenever the vital properties of the blood are impaired, and the formative process diminished, whether from disease of the lungs, the respiration of impure air, exposure to cold, over-exertion of body or mind, imperfect nourishment, excessive medication or the depressing emotions, the power of resisting the various causes of disease, (the *vis conservatrix naturæ,*) of uniting wounds, and restoring lost parts, is proportionally reduced. *Nor is it*

possible that any general disease could exist so long as the blood is constantly renovated by respiration, and depurated by excretion from the lungs, skin, kidneys and bowels. In fact, the very existence of man, like that of the entire universe, is preserved by a continual creation. Nor is it unworthy of notice, that the formation of blood is immediately connected with the process of combustion, by which caloric is evolved, and all the operations of life carried on. The process of oxidation by which rocks, salts and other bodies are formed, is also one of slow combustion, by which subterranean heat is evolved, volcanos, earthquakes and hot springs produced, and islands, mountains and continents gradually raised from beneath the ocean. The decay of dead animal and vegetable matter is equally a process of combustion, by which new combinations are created. Lastly, all artificial light and heat are obtained by the same process, which is doubtless the origin of solar radiation; so that all the operations of the material universe are ultimately resolvable into combustion, which depends on the agency of heat.

The circulation of arterial blood from the heart throughout all parts of the animal frame is somewhat analogous to the distribution of water from the ocean through the atmosphere by evaporation: and the return of the same water to the fountain whence it sprung, by innumerable rivers, resembles the return of venous blood to the heart. The deposition of sedimentary rocks from a state of solution in the water of lakes and seas, is also somewhat analogous to the process of nutrition, by which the composition of animals

is renewed; while the removal of the effete portions of the body by absorption and elimination, is similar to the wearing away of mountains, hills and elevated plains, by the corroding action of running water and chemical decomposition.

If then it be true, that the aggregate vital energy of animals and the development of their whole organization, are in proportion to the quantity of caloric they derive from the atmosphere by respiration, it must be the cause of their vital activity and growth. Or if the faculty of sensation be annihilated by the abstraction of animal heat from the nervous system, it must be the sentient principle. And if the velocity of planets through their orbits diminishes in proportion to their distance from the sun, it is self-evident that their lasting motions would very soon come to an end, in the total absence of solar radiation. But as their centrifugal force is maintained by the perpetual radiation of caloric from the centre toward the circumference of the system, so is the centripetal force by which they are preserved in their respective orbits, maintained by the unceasing flow and pressure of the same great ethereal tide to the solar fountain from which it emanates.

Again, if it be true, as I have demonstrated, that the mobility and organizing power of matter are in proportion to the quantity of caloric around its atoms, and that these powers are diminished by every abstraction of caloric, or reduction of temperature, it follows, that in the total absence or privation of that principle, (if such a condition were possible,) the atoms of ponderable matter would be perfectly inert,

and there could be no attraction, repulsion, contraction and expansion of matter.

It was nobly said by Bacon, that "the highest ambition of man should be the discovery of some one thing by which all others might be discovered;" and that "science, rightly interpreted, is the knowledge of things through their causes." Nor can there be a rational doubt, that a complete knowledge of the *Prime Mover* would afford a key by which to unloose the seals of the book of nature, and open the gates that lead to the inner temple of her most hidden mysteries. But owing to the paralyzing influence of custom, prejudice of education and a dread of encountering the throned opinions of the world, few have had the boldness to inquire with unreserved freedom into the primary cause of phenomena. The consequence of which has been, that the strength of many an intellectual giant has been wasted in fruitless efforts.

END OF VOL. I.